A TEXT-BOOK OF BOTANY

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SUPERINTENDENT OF SCHOOLS, COOK COUNTY, ILLINOIS

TEXT-BOOKS IN BOTANY

By John M. Coulter, Ph.D.

HEAD OF DEPARTMENT OF BOTANY IN THE UNIVERSITY OF CHICAGO

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TWENTIETH CENTURY TEXT-BOOKS

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A TEXT-BOOK OF BOTANY

FOR SECONDARY SCHOOLS

BY

JOHN M. COULTER, A. M., PH. D.

HEAD OF DEPARTMENT OF BOTANY, THE UNIVERSITY
OF CHICAGO

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PREFACE

THE several editions of *Plant Studies*, designed for use in secondary schools, were combined abridgments of *Plant Relations* and *Plant Structures*. Although this arrangement involved a certain amount of repetition and lack of continuity, it was felt that these faults would be corrected by the competent teacher, whose chief desire would be to secure points of view in reference to botanical material.

During the five years that have elapsed since the publication of the first edition of *Plant Studies*, the opinions of many experienced teachers have been obtained. These opinions have been based upon repeated use of the book, and have been of the greatest possible service in developing definite ideas as to the adjustment of the subject to the needs of the schools. The natural outgrowth of this coöperation between author and teachers has been the preparation of the present *Text-Book of Botany*, which seeks to express their combined judgment. There has been substantial agreement as to the nature of the material and the points of view, the only differences of opinion being such minor ones of presentation as must always be found among equally competent teachers.

There has been no attempt to treat the various divisions of Botany separately, but rather to develop them all in their most natural relationships; and yet morphology, physiology, and ecology have been kept so distinct that the teacher will have no difficulty in calling attention to these divisions, if it is thought desirable.

In the first five chapters the structure, function, and relationships of the most obvious plant organs are considered. The purpose has been to use the most easily observed material to give preliminary training in observation and some conception of the activities of plants.

The following thirteen chapters present an outline of the plant kingdom in the simplest possible form to be at all adequate. In these chapters the morphological point of view necessarily dominates, but not to the exclusion of the physiological and ecological. In this presentation of the great groups, which is also an outline of classification, there have been included special accounts of forms of economic interest; not only because such forms as well as any others may illustrate groups, but chiefly because there is a growing conviction that Botany in the schools must relate pupils to their common experiences, as well as train them in science. For the same general reason the brief chapters on plant-breeding and forestry have been introduced.

The four closing chapters include a very brief account of plant associations, the most inclusive view of plants. This subject is merely introduced rather than developed.

It cannot be repeated too often that this book will not serve its purpose unless it is used as a supplement to the teacher, to the laboratory, and to field-work. Furthermore it must be insisted that the sequence of the book need not be the sequence used by the teacher. For example, work on leaves, stems, roots, and seeds may come in any order, and may well differ according to the availability of material or the conviction of the teacher. It so happens that the book begins with leaves, but those teachers who prefer to begin with seeds should do so.

In the matter of illustrations, there have been many improvements, eliminations, and additions. All of this work has been done or directed by my assistant, Dr. W. J. G. Land, whose skill in photography has been made use of freely and whose coöperation has added much to the value of the book. Unless otherwise credited, all illustrations have been prepared for this volume or those previously mentioned.

JOHN M. COULTER.

THE UNIVERSITY OF CHICAGO,
September, 1905.

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A TEXT-BOOK OF BOTANY
FOR SECONDARY SCHOOLS

CHAPTER I

INTRODUCTION

1. Occurrence of plants.—Plants form the natural covering of the earth's surface. So generally is this true that a land surface without plants seems remarkable. Not only do plants cover the land, but they abound in waters as well, both fresh and salt waters. One of the most noticeable facts in regard to the occurrence of plants is that they do not form a monotonous covering for the earth's surface, but that there are forests in one place, meadows in another, swamp growths in another, etc. In this way the general appearance of vegetation is exceedingly varied, and each appearance tells of certain conditions of living.

2. **Plants as living things.**—It is very important to begin the study of plants with the knowledge that they are alive and at work. It must not be thought that animals are alive and plants are not. There is a common impression that to be alive means to have the power of locomotion, but this is far from true; and in fact some plants have the power of locomotion and some animals do not. Both plants and animals are living forms, and the laws of living that animals obey must be obeyed also by plants. Of course there are differences in detail, but the general principles of living are the same in all living forms. To begin with the

thought that plants are alive and at work is important because this fact gives meaning to their forms and structures and positions. For example, the structure of a leaf has no meaning until it is discovered how its structure enables the leaf to do its work.

3. **The plant body.**—Every plant has a body, which may be alike throughout or may be made up of a number of different parts. If one part of the body does not differ from another, the plant is said to be *simple;* but the most conspicuous plants, those with which every one is best acquainted, are made up of dissimilar parts, such as root, stem, and leaf, and such plants are said to be *complex.* Simple and complex plants do the same work; but in the simple plant the whole body does every kind of work, while in the complex plant different kinds of work are done by different regions of the body, and these regions come to look unlike when different shapes are better suited to different kinds of work, as in the case of leaf and root.

4. **Plant organs.**—The different regions of the plant body thus set apart for special purposes are called *organs;* and complex plants have several kinds of organs, just as the human body has hands, feet, eyes, etc. The advantage of this to the plant becomes plain by using the common illustration of the difference between a tribe of savages and a civilized community. The savages all do the same things, and each savage does everything. In the civilized community some of the members are farmers, others bakers, others tailors, others butchers, etc. This is known as "division of labor," and one great advantage it has is that every kind of work is better done. Several kinds of organs in a plant mean to the plant just what division of labor means to the community; it results in better work and more work.

5. **Plant work.**—Although many different kinds of work are being carried on by plants, all the work may be put

under two heads: *nutrition* and *reproduction*. This means that every plant must care for two things: (1) the support of its own body (nutrition) and (2) the production of other plants like itself (reproduction). To the great work of nutrition many kinds of work contribute, and the same is true of reproduction. In a complex plant, therefore, there are nutritive organs and reproductive organs; and this means that there are certain organs which specially contribute to the work of nutrition, and others which are specially concerned with the work of reproduction. It must not be supposed that an organ is necessarily limited to one kind of work. Its form and structure fit it for a particular kind of work, which may be called its specialty; but it is not excluded from other kinds of work, just as a man who is specially trained to be a carpenter may do other things also.

6. **Life-relations.**—In all of its work a plant is very dependent upon its surroundings. For example, it must receive material from the outside and get rid of waste material. Therefore, organs must establish certain definite relations with things outside of themselves before they can work effectively; and these necessary relations are known as *life-relations*. For example, green leaves are definitely related to light—they cannot do their peculiar work without it; many roots must be related to the soil; certain plants are related to abundant water; some plants are related to other plants, as parasites, etc. It is evident that a plant with several organs may hold a great variety of life-relations, and it is a very complex problem for such a plant to adjust all of its parts properly to their most effective relations. It must not be supposed that even a single organ holds a perfectly simple life-relation, for it is affected by a great variety of things. For example, a root is affected by gravity, moisture, soil material, contact, etc. Each organ, therefore, must become adjusted to a complex set of rela-

tions; and a plant with several organs has so many delicate adjustments to care for that it is impossible, as yet, for us to explain why all of its parts are placed just as they are.

7. **Some conspicuous organs.**—The prominent plants, which are spoken of as herbs, shrubs, and trees, have three conspicuous organs, *root*, *stem*, and *leaf*, which are concerned with nutrition; and most of these plants have at some time also another structure, the *flower*, which is concerned with reproduction. Our first attention will be given to these three great nutritive organs. A tree, for example, has its roots extending more or less widely through the soil; from the roots a stem rises into the air and branches more or less extensively; and upon this stem or its branches leaves are borne. Such is the general plan of the more complex plants; and our first purpose will be to discover what these organs are doing, and why they are so related to one another and to their surroundings.

CHAPTER II

LEAVES

8. **Arrangement.**—Leaves appear upon the stems at definite regions called *nodes* (joints); and this jointed structure of the stem is one of its characteristic features, although it is much more conspicuous in some plants than in others. In certain plants only one leaf appears at each node; and if an imaginary line be drawn connecting the points on the nodes at which successive leaves appear, it

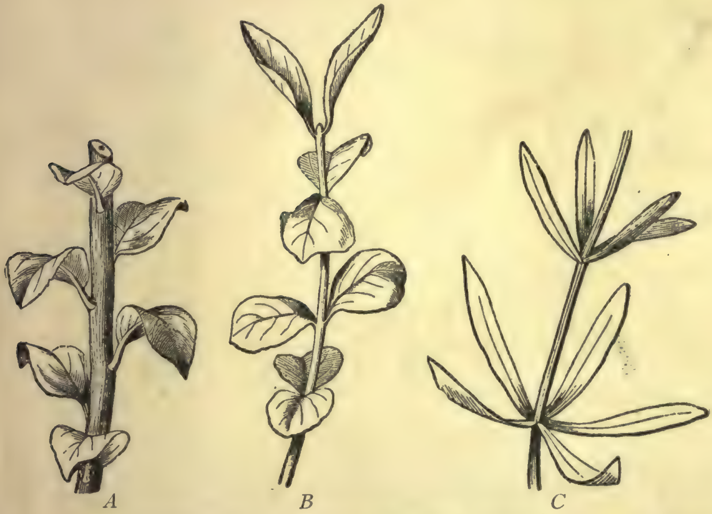

FIG. 1.—Leaf arrangement: *A*, spiral or alternate leaves; *B*, opposite (cyclic) leaves; *C*, whorled (cyclic) leaves.—After GRAY.

will form a spiral winding about the stem (Fig. 1, *A*). As a consequence, leaves with this arrangement are said to be *spiral*, though they are still often called *alternate*. On account of this spiral arrangement, two successive leaves are in different vertical planes, and the danger of the upper leaf shading the lower is reduced. In other plants two or more leaves appear at each node; and as an imaginary line connecting their points of origin forms a circle about the stem, the arrangement is called *cyclic*. Very commonly, however, when two leaves appear at a node they are said to be *opposite* (Fig. 1, *B*); and when more than two appear they are described as *whorled* (Fig. 1, *C*). The cycle of leaves at one node does not stand directly over the cycle at the node below, but over the spaces between the lower leaves, the danger of shading being reduced as in the case of the spiral arrangement. In fact, the cyclic arrangement differs from the spiral only in having two or more parallel spirals.

9. **Regions.**—The conspicuous part of a leaf is the expanded portion known as the *blade*, and often the leaf is all blade. In many cases the leaf has a stalk (*petiole*) which bears the blade more or less away from the stem; and in certain groups of plants a third region is evident, usually consisting of a pair of more or less blade-like appendages (*stipules*) on the petiole where it joins the stem (Fig. 2, *A*). As might be expected, the essential part of the leaf is the blade, and ordinarily when the word leaf is used it refers to the blade.

10. **Venation.**—Upon examining an ordinary leaf, the blade is seen to consist of a green substance through which a network of veins is variously distributed The larger veins that enter the blade send off smaller branches, and these send off still smaller ones, until the smallest veinlets are invisible. This is plainly shown by a skeleton leaf; that is, one which has been so treated that all the green substance has disappeared. and only the network of veins

remains. The vein-system or *venation* of leaves is exceedingly diverse, but all forms can be referred to a few general plans.

In some leaves a single very prominent vein runs through the middle of the blade, and is called the *midrib*. From this all the minor veins arise as branches, and such a leaf is said to be *pinnately veined* (Fig. 2, *A*, and Fig. 9). In other leaves several large veins (*ribs*) of equal prominence enter the blade and diverge, each giving rise to smaller branches. Such a leaf is said to be *palmately veined* (Fig. 2, *B*, and Fig. 16). In still other leaves all the visible veins run approximately parallel from the base of the blade to its apex, such leaves being *parallel-veined* (Fig. 2, *C*), as distinct from the two preceding, which are both *net-veined*.

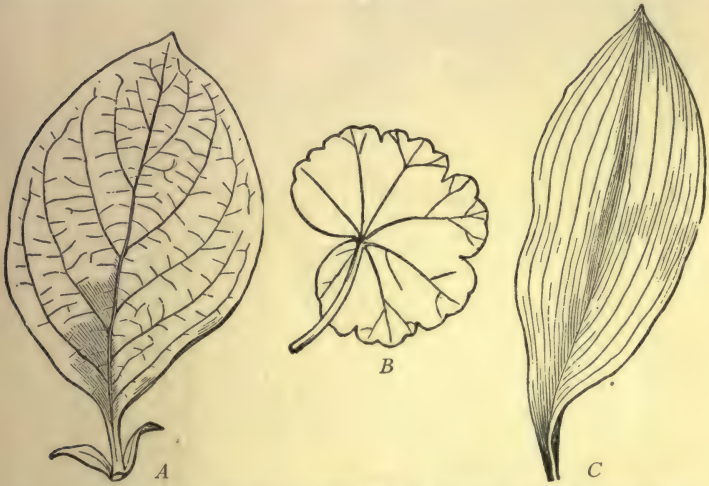

Fig. 2.—Venation: *A*, pinnately veined leaf of quince, showing blade, petiole, and stipules; *B*, palmately veined leaf of geranium; *C*, parallel-veined leaf of lily-of-the-valley.—After Gray.

11. **Form.**—The forms of leaves are exceedingly varied and are related to their venation. Palmately veined leaves

incline to broader forms than leaves pinnately veined or parallel-veined. Names have been given to the various leaf forms, as *linear, lanceolate, ovate, orbicular*, etc., but they can be learned as they are needed. In the net-veined leaves the margin of the blade may be more or less deeply *toothed* or *lobed* (Fig. 2, *B*); but in the parallel-veined leaves the margin is not at all toothed, in which case the leaf is said to be *entire* (Fig. 2, *C*). It is quite common also for net-veined leaves to branch, when they are said to be *compound*. In this case the leaf-blade is broken up into a number of small blades, sometimes very many of them, called *leaflets*. A branching pinnate leaf is said to be *pinnately compound* (Fig. 3, *A*); and a branching palmate leaf, *palmately compound* (Fig. 3, *B*).

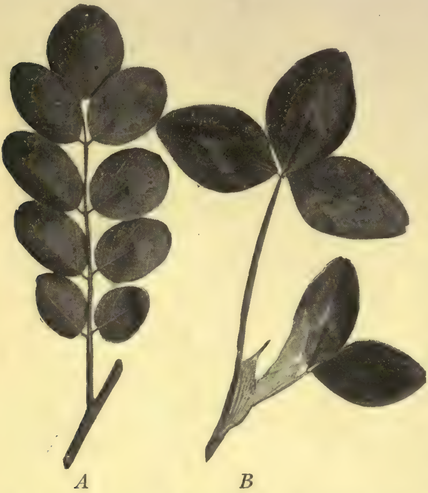

FIG. 3.—Compound leaves: *A*, pinnately compound leaf of black locust; *B*, palmately compound leaf of red clover, with three leaflets, also showing stipules.

12. **Exposure to light.**—The special work of leaves is exceedingly important, and this work cannot be done unless the leaf is exposed to light. This fact explains many things in connection with the position and arrangement of leaves. Leaves must be arranged to receive as much light as possible to help in their work, but too intense light is dangerous; hence the adjustment to light is a delicate one. The exact position any particular leaf holds in relation to light, therefore, depends upon many circumstances, and

cannot be covered by a general rule, except that it seeks to get all the light it can without danger. How leaves seek the light will be first considered, and later how they protect themselves against it.

(1) *Horizontal position.*—The ordinary position of the leaf is more or less horizontal. This enables it to receive the direct rays of light upon its upper surface, and more rays strike it than if it stood obliquely or on edge. Most leaves when fully grown are in a fixed position and cannot change it, however unfavorable it may become; but there are leaves so constructed that they can shift their position as the direction of the light changes, or the stem bearing the leaves may shift its position so that a better relation to light is secured (Fig. 4). If a garden nasturtium growing in a window be observed, its leaves will be seen facing the

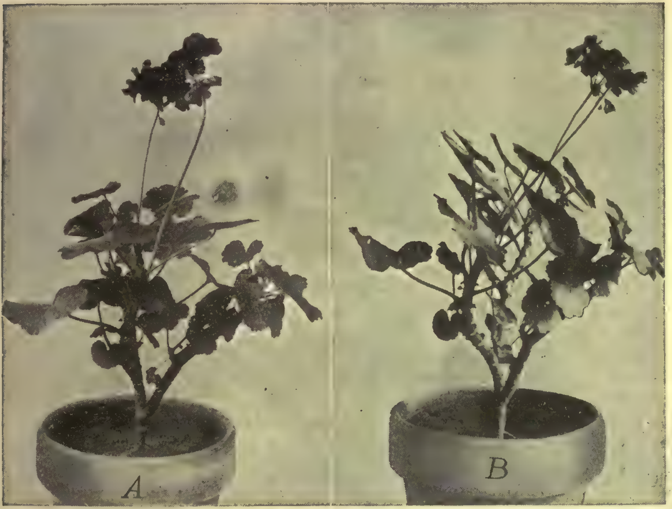

Fig. 4.—Geranium leaves exposed first to vertical (*A*) and then to oblique (*B*) rays of light.

light; but if it be turned around so as to bring the other side of the plant to the light, the leaves will become adjusted gradually to the new direction. Many plants have more or less power to direct their leaves, and it would be interesting to observe what common plants of any region possess it.

(2) *Problem of shading.*—It is evident that leaves of the same plant are in danger of shading one another; and while it cannot always be prevented, there are ways by which the danger is diminished. The problem of the plant is to develop as much leaf surface as possible and to place it in the most favorable position for work. The spiral arrangement of leaves prevents two successive leaves standing in the same plane, and results in vertical rows of leaves distributed about the stem. The narrower the leaves, the more numerous may be the vertical rows; and the broader the leaves, the fewer the vertical rows (Fig. 5). In many herbs whose leaves are rather large and close together, the petioles of the lower leaves are usually longer than those above, and thus their blades are thrust beyond the shadow. The same result is obtained when the lowest leaves of a plant

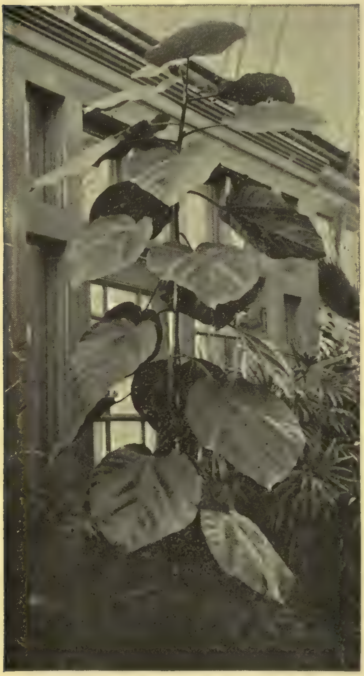

FIG. 5.—A broad-leaved plant, showing few vertical rows, and variously directed leaves.

are the largest, and the upper leaves gradually diminish in size.

(3) *Rosette-habit.*—An extreme case of crowding is shown by plants with the rosette-habit; that is, those which produce a cluster or rosette of leaves at the base of the stem (Figs. 6 and 7). Often this rosette, frequently lying flat upon the ground or upon the rocks, includes all the leaves the plant produces. This close overlapping of leaves is a poor adjustment to light at best, but there is evident an adjustment to secure the most light possible under the circumstances. The lowest leaves of the rosette are the longest, and the upper ones become gradually shorter, so that each leaf has at least a part of its surface exposed to light.

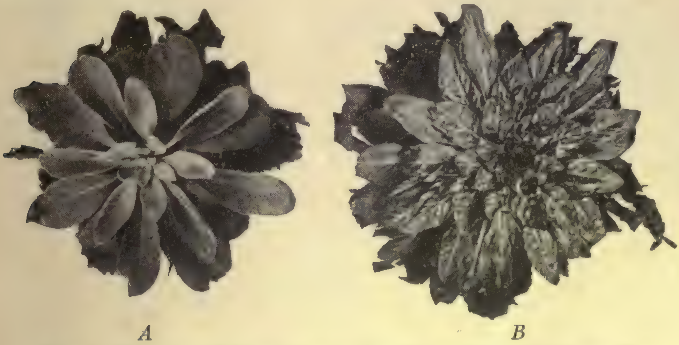

Fig. 6.—Rosette-habit shown by mullein (*A*) and evening-primrose (*B*).

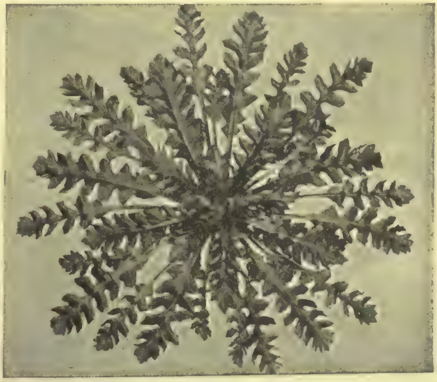

Fig. 7.—Rosette-habit shown by shepherd's purse.

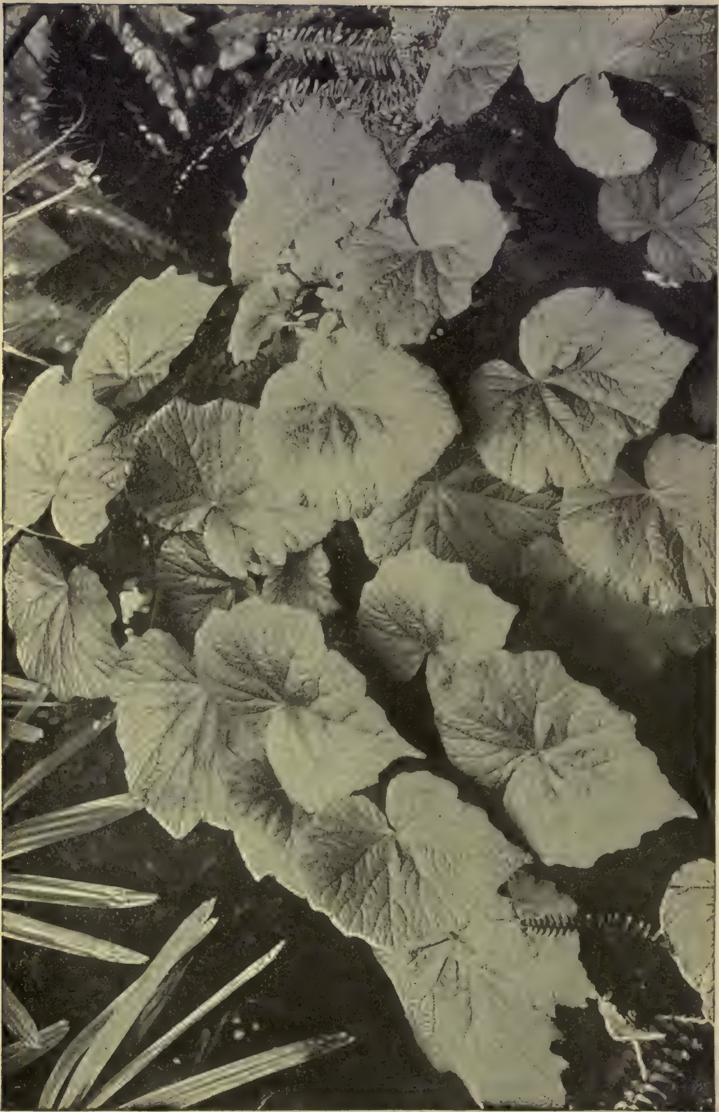

Fig. 8.—Leaves of *Begonia* showing mosaic arrangement.

The overlapped base is not expanded so much as the exposed apex, and hence such leaves are usually narrow toward the base and broad toward the apex. This narrowing at the base is sometimes carried so far that most of the overlapped part is only a petiole.

(4) *Leaf-mosaics.*—All leaf adjustments (including the spiral arrangement, elongation of lower petioles, etc.) that have to do with fitting leaf-blades together, so that the greatest amount of leaf surface may be exposed to direct illumination, may be regarded as concerned in the construction of a *leaf-mosaic.* A general mosaic arrangement of leaves may be observed in connection with almost every broad-leaved plant (Figs. 8 and 9); and even when the leaves are separated along an erect stem, a view from above,

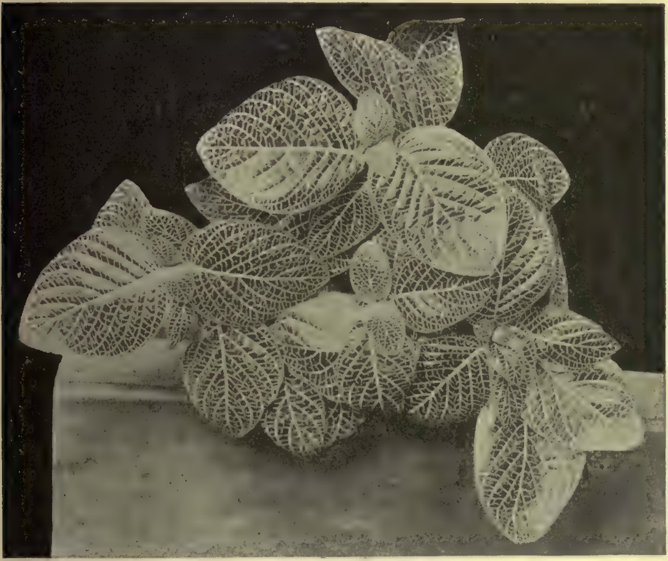

FIG. 9.—Leaves of *Fittonia* showing mosaic arrangement.

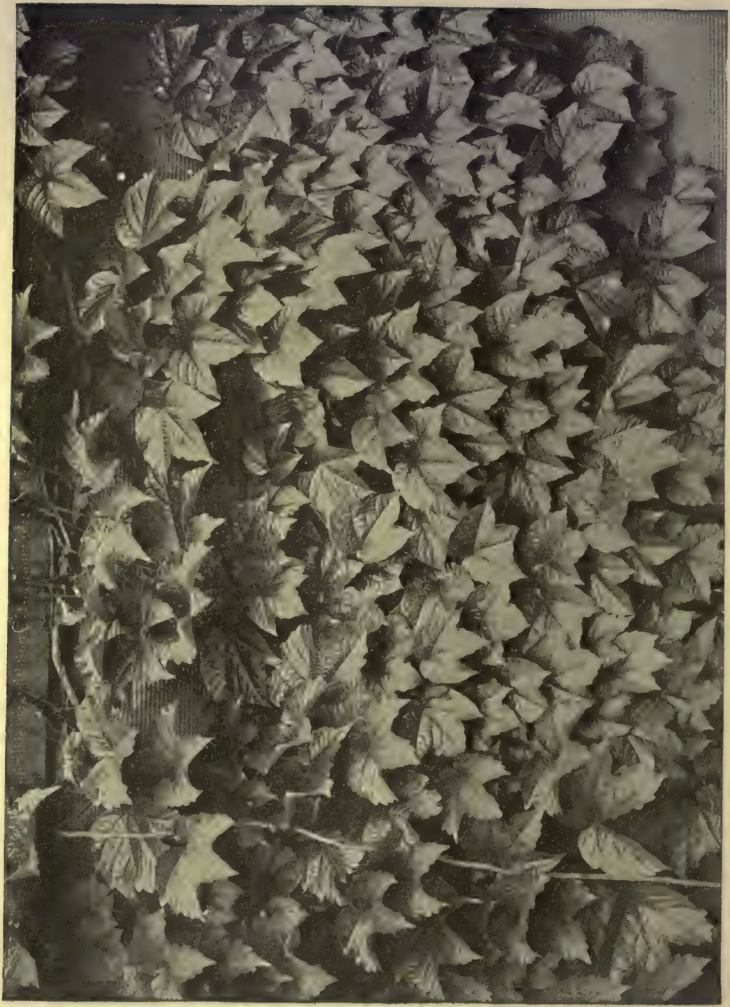

FIG. 10.—A leaf-mosaic of ivy (*Ampelopsis*).

in which all the leaves are referred to a single plane, shows the mosaic. In many trees in dense forests, notably in the tropics, the leaves appear chiefly and sometimes exclusively at the extremities of the branches, often producing a magnificent dome-like mosaic.

In the case of stems exposed to direct light only on one side, as the horizontal branches of trees, stems prostrate on the ground, and stems against a support (as climbers and twiners), the leaf-blades must be brought to the light side so far as possible, and those that belong to the shaded side must be fitted into the spaces left by those that belong to the illuminated side. This is brought about in various ways, as by the twisting of the stem, the twisting and elongation of the petiole, the bending of the blade on the petiole, etc. Looking up into a tree in full foliage, one will notice that the horizontal branches are comparatively bare beneath, the leaf-blades being displayed on the upper side as a mosaic. The most complete leaf-mosaic is shown by certain ivies, involving such an amount of twisting, displacement, elongation of petioles, etc., as to give ample evidence of the importance of securing for leaves an exposure to light (Fig. 10).

13. **Structure.**—Before considering the work of the leaf it will be necessary to know something of its minute structure. To see this structure, not merely surface views must be obtained, but also good clear sections through the leaf (cross-sections) must be made; and for this purpose a relatively thick spongy leaf, like that of the hyacinth or the lily, gives the least trouble.

(1) *Epidermis.*—It is possible to peel off from the surface of such a leaf a delicate transparent skin (*epidermis*). This epidermis completely covers the leaf, and generally shows no green color. Examined under the compound microscope it is seen to be made up of small units of structure known as *cells* (Fig. 11). Each cell is bounded

by a wall, and in the epidermis these cells fit closely together, sometimes dovetailing with one another.

Characteristic openings in the epidermis also will be discovered, sometimes in very great numbers. Guarding each slit-like opening are two crescent-shaped epidermal cells, called *guard-cells* (Fig. 11). The whole apparatus is known as a *stoma* (plural *stomata*), which really means "mouth," of which the guard-cells might be thought of as the lips. One important fact about stomata is that the guard-cells can change their shape, and so vary the size of the opening. These numerous openings are passageways into the interior of the leaf, putting the internal cells into communication with the air outside, and so facilitating the interchange of gases that will be described later in connection with the work of the leaf. In horizontal leaves the stomata are chiefly and sometimes exclusively on the lower surface, a fair average number being about 100 to each square millimeter of surface (about 62,500 to the square inch); although in some cases the number may reach 700 to the square millimeter (almost 450,000 to the square inch). In leaves exposed alike on both sides to the light, as in the erect leaves of the common flag, the stomata are equally distributed on both surfaces. In floating leaves, as those of water-lilies, the stomata are all on the upper surface; and in submerged leaves there are no stomata. From this dis-

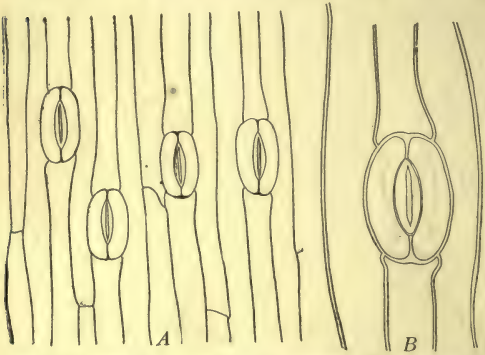

Fig. 11.—Surface view of the epidermis of a hyacinth leaf: *A*, epidermal cells and four stomata with their guard-cells; *B*, enlarged view of a single stoma.

tribution it is evident that stomata are definitely related to air; and that where there is difference of illumination on the two surfaces they occur chiefly on the less illuminated surface. Stomata are not peculiar to the epidermis of leaves; for they are found in the epidermis of any green part, as young stems, fruit, etc., and even on the colored parts of flowers.

(2) *Mesophyll.*—A cross-section of a leaf such as that of the lily shows the single layer of epidermal cells bounding the section above and below, pierced here and there by stomata, recognized by their guard-cells (Fig. 12). An enlarged view of a section of a single stoma may be seen in Fig. 20. Between these two epidermal layers is the mass of green tissue making up the body of the leaf, and known as *mesophyll*. This comprises cells containing the numerous small green bodies (*chloroplasts*) that give color to the whole leaf. Usually the mesophyll cells are arranged differently in the upper and lower regions of the horizontal leaf. In the upper region the cells just beneath the epidermis are elongated at right angles to the surface of the leaf, and stand in close contact, forming the *palisade tissue*. In the lower region of the leaf the cells

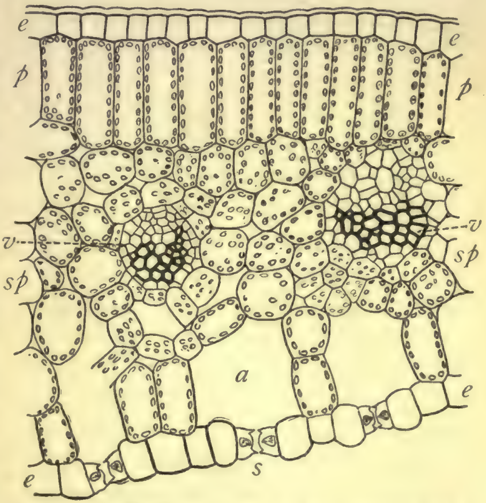

Fig. 12.—Cross-section of a lily leaf, showing epidermal layers (*e*) with stomata (*s*); mesophyll made up of palisade tissue (*p*) and spongy tissue (*sp*) with air-spaces (*a*), and containing chloroplasts; and sections of veinlets (*v*)

are irregular in form, and so loosely arranged as to leave *air-spaces* between the cells, the whole region forming the *spongy tissue* (Fig. 12). The air-spaces communicate with one another, thus forming a labyrinthine system of air-chambers throughout the spongy mesophyll. It is into this system of air-chambers that the stomata open, and thus what may be called an internal atmosphere is in contact with all the green working cells, and this internal atmosphere is in free communication through the stomata with the external atmosphere. The significance of the palisade arrangement will be considered under the head of leaf protection.

(3) *Veins.*—In the cross-section of the leaf there will be seen also here and there, embedded in the mesophyll, the cross-sections of veins and veinlets, that constitute the supporting framework of the leaf and conduct material to and from the green working cells (Fig. 12).

14. **Photosynthesis.**—The peculiar work of green plants or green parts of plants is to manufacture the kind of food best known as sugars and starch, such foods being called *carbohydrates.* This manufacture is exceedingly important, for all life is dependent upon it. If green plants should stop the manufacture of carbohydrates, the food supply of the world would soon be exhausted. All other forms of food are derived from carbohydrates in some way, and only green plants can add to the stock that is being drawn upon continually. This means that green plants must manufacture carbohydrates not only for their own use, but also for the use of animals and of plants that are not green. Since leaves are chiefly expansions of green tissue, they are conspicuous in the manufacture of carbohydrates; but it must be remembered that the manufacture goes on wherever there is green tissue, whether it is found in leaves or not.

A very conspicuous fact about this manufacture is that it cannot go on unless the green tissue is exposed to light.

This explains why leaves are adjusted in so many ways to obtain light, as described in § 12. It also gives name to the process, *photosynthesis*, the name indicating that the work is done in the presence of light.

The process demands that carbohydrates shall be made from raw materials common in nature and easily obtained by plants, and in photosynthesis two such substances are used. One of these is water, which in the plants commonly thought of is absorbed by the roots from the soil, passes up through the stem, and reaches the green working cells of the leaves through the veins. The other substance is carbon dioxide, a gas present in small proportion in the air (really in the form of carbonic acid gas), but one which is being constantly renewed as it is used, so that it is always available. Water is made up of one part of oxygen and two parts of hydrogen; while carbon dioxide consists of two parts of oxygen and one part of carbon. These are just the elements that enter into the structure of a carbohydrate.

In photosynthesis the elements of water and carbon dioxide are separated and recombined to form a carbohydrate, and when this has been accomplished it is found that some oxygen has been left over. That is, in the process oxygen is a waste product and is given off by the working cells. Therefore, in the sunlight a leaf is absorbing carbon dioxide and giving off oxygen; and this gas exchange is the superficial indication that photosynthesis is going on.

It is very easy to discover that oxygen is being given off by a leaf exposed to light, and that the amount given off (and hence the amount of work) depends upon the intensity of the light. If an actively growing water-plant, submerged in water in a glass vessel, be exposed to bright light, bubbles may be seen coming from the plant and rising through the water (Figs. 13 and 14). Shading the vessel diminishes the number of bubbles. That the gas being given off is mainly oxygen may be proved by invert-

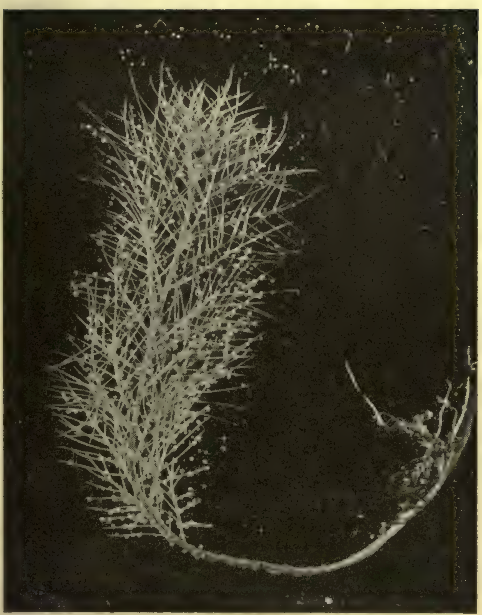

Fig. 13.—A submerged water-plant (*Proserpinaca*) giving off bubbles of oxygen upon exposure to light.

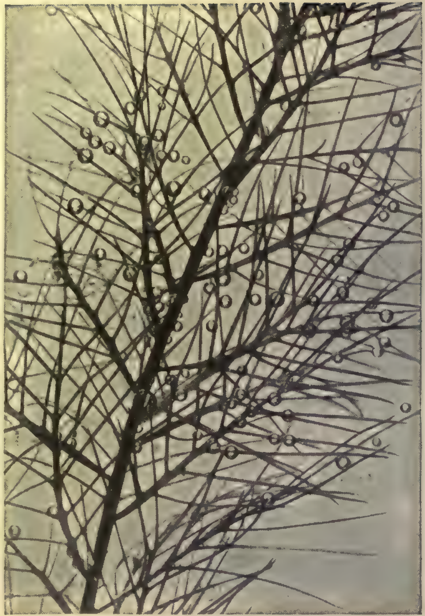

Fig. 14.—An enlarged view of a small portion of Fig. 13.

ing over the plants a large funnel and leading the bubbles into a test tube, in which the presence of oxygen can then be tested.

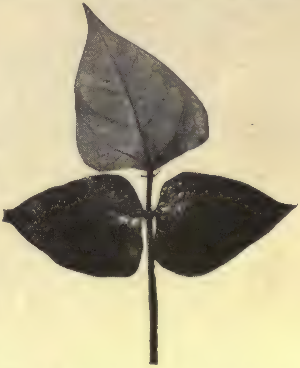

FIG. 15.—A bean leaf whose terminal leaflet has been covered and whose lateral leaflets have been exposed to light; the test shows an absence of starch in the former and an abundance of it in the latter.

It has been noted that photosynthesis is associated not merely with light but also with green tissue; and in examining the structure of the leaf it was discovered (§ 13) that the green color is due to the presence of chloroplasts in the mesophyll cells. It is these chloroplasts that manufacture the carbohydrates, and they obtain from the light the power (energy) to do it. The first visible product of photosynthesis is starch, and when the working cells are very active starch may be observed to accumulate in them; but when the process becomes slower or stops, as during the night, this starch disappears, the food being carried away for use (Figs. 15 and 16).*

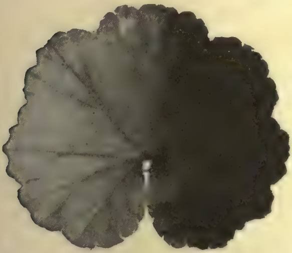

FIG. 16.—A geranium leaf, one-half of which has been covered; the test shows absence of starch in the covered half.

A summarized statement of photosynthesis is as follows: It is the manufacture of carbohydrates by chloroplasts in the presence of light, water and carbon dioxide being used, and oxygen being given off as a waste product.

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* Experiments should be devised to test for the accumulation of starch in leaves that have been exposed for some time to a strong light, and to show that this accumulation does not take place in the dark. In the experiments illustrated by Figs. 15 and 16, the test for starch was

15. Transpiration.—Water is being evaporated constantly from the surface of a living plant exposed to the air. This loss of water by the plant has been called *transpiration.* Since leaves are especially exposed to the air, their transpiration is conspicuous. Although the epidermis impedes transpiration, we have seen (§ 13) that the leaf has in its system of air-spaces an internal atmosphere, which is in communication with the external atmosphere through the stomata. Hence, water vapor is constantly passing from the working cells into the internal atmosphere and diffusing through the stomata into the external atmosphere. Although a certain amount of transpiration takes place directly through the epidermal cells, much the larger part of the water vapor passes out by way of the stomata. If the stomata are closed by the guard-cells, the internal atmosphere becomes saturated with water vapor and transpiration ceases. It is evident that the larger the air-spaces in the leaf, that is, the looser the leaf is in texture, the greater is the amount of internal atmosphere, and the more rapid is transpiration. Hence the amount of transpiration from a leaf depends more upon its structure than upon the extent of its exposed surface.

If a glass vessel (bell jar) be placed over a small active plant, the moisture is seen to condense on the glass, and even to trickle down the sides (Fig. 17).* When the

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as follows: After the exposure to light, the leaves were placed in alcohol to extract the green coloring matter (*chlorophyll*). When this was accomplished, they were rinsed thoroughly, to remove the alcohol, and placed in a water solution of iodine. In this solution the starch-containing portion becomes dark blue, the other portion remaining colorless. The water solution of iodine is obtained by dissolving potassium iodide in water and adding scales of iodine.

* Some such experiment should be performed to demonstrate the fact of transpiration. Care must be taken to shut off the evaporation from the pot or soil, since it is to be demonstrated that water is coming from the plant. Rubber cloth or a coating of paraffin or wax may be used for sealing up all sources of moisture except the plant (Fig. 17).

amount of water given off by a few leaves is noted, some vague idea may be formed as to the amount given off by a great mass of vegetation, such as a meadow or a forest. One observer has stated that a single stalk of corn during its life (173 days) transpired about four gallons of water; and that a single hemp plant (140 days) transpired nearly eight gallons. Another observer estimated that a sunflower, whose leaf surface was approximately nine square yards, gave off nearly one quart of water in a single day.

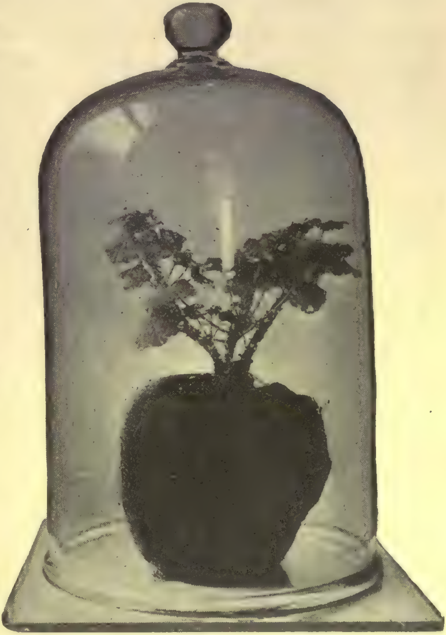

FIG. 17.—Transpiration experiment: a potted geranium sealed with a rubber cloth and covered with a bell jar; the mist and droplets of water on the glass more or less obscure the plant.

16. **Growth.**—In very young leaves growth takes place at the apex, but this may cease early. The subsequent growth often occurs at the base of the blade, in a special growing region, as may be seen in long and narrow leaves such as those of grasses. To discover these special regions of growth in leaves, some rapidly growing plants (such as the gourds) should be cultivated in pots. When the young leaves first appear, a scale should be marked off in India ink with a pointed camel's hair brush on the petiole (if there be one) and the midrib. The scale should be made

with definitely spaced lines, preferably five millimeters apart.* As the leaf continues to grow, the most active growing region will be indicated by the lines that draw farthest apart.

17. **Protection.**—Such an important organ as the leaf, with its delicate active cells necessarily in communication with the air, is exposed to numerous dangers. Conspicuous among these dangers are drought, intense light, and cold. Many ways of meeting these dangers have been developed by plants, but the subject is too large and complex to be presented with any completeness. The best that can be done is to select a few striking illustrations of protection that seem to be definite. Perhaps the most common danger to most plants is an excessive loss of water, and when a drought prevails the problem of checking transpiration is a most serious one. As the leaves are the prominent transpiring organs, the chief methods of protection concern them.

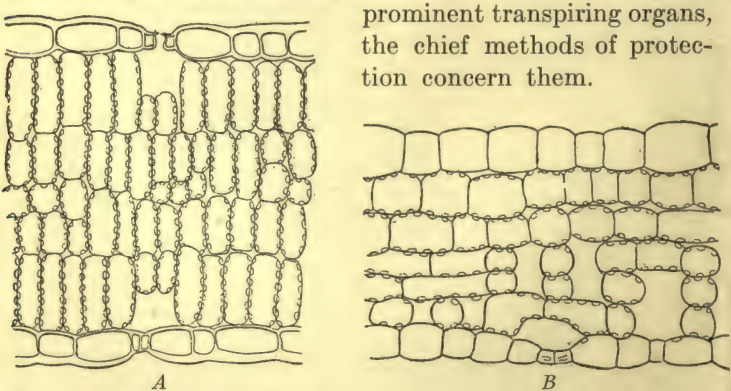

FIG. 18.—Sections through leaves of the same plant, showing the effect of exposure to light upon the structure of the mesophyll: *A*, leaf exposed to intense sunlight; *B*, leaf grown in the shade.—After STAHL.

(1) The *epidermis* may be regarded as an ever-present check against transpiration (Fig. 12), for without it the

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* Such scales on stem and root are seen in Figs. 57 and 75.

active mesophyll cells would soon lose all their water. In some plants of very dry regions, what may be regarded as several epidermal layers appear.

(2) The *palisade layer* of the mesophyll (§ 13) also is very commonly present and tends to diminish transpiration, exposing only the ends of elongated cells, which stand so close together that there is no drying air between them (Fig. 12). It is very characteristic of alpine and desert plants to form two or three layers of palisade cells, apparently as a protection against unusual danger from drought and intensity of light. The accompanying figure (Fig. 18) shows in a striking way the effect of light intensity upon the structure of mesophyll, by contrasting leaves of the same plant exposed to extreme conditions of light and shade. The intense light is dangerous to the chloroplasts, and it has been observed that they are able to assume various positions, in very intense light moving to the more shaded depths of the palisade cells, and in less intense light moving to the more external regions of the cell.

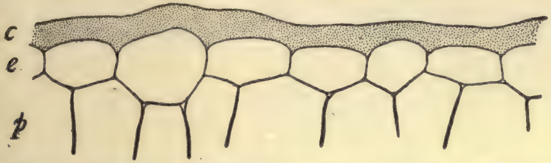

FIG. 19.—Section through a small portion of yew leaf, showing the epidermal layer (*e*) with its cuticle (*c*), and the upper portion of the palisade layer (*p*).

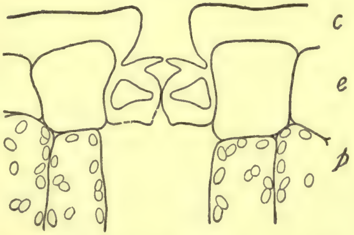

FIG. 20.—Section through a small portion of carnation leaf, showing the epidermal cells (*e*) with their heavy cuticle (*c*); a single stoma in the epidermal layer, opening without into a broad passageway through the cuticle, and within into an air-chamber; and the upper portion of palisade cells (*p*) containing chloroplasts.

(3) The *cuticle*, which is often developed upon the epidermis, is one of the best protections against loss of water. It is developed by the exposed walls of the epidermal cells, and being constantly renewed from beneath it may become very thick and many-layered (Fig. 19). Sometimes the cuticle becomes so thick that the passageways through it to the stomata resemble tubes (Fig. 20). In dry regions, or in any much exposed place, the cuticle is a very constant feature of plants.

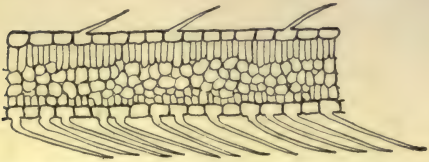

FIG. 21.—Section through the leaf of bush clover, showing upper and lower epidermis, palisade cells, and cells of the spongy tissue; the lower epidermis produces numerous simple hairs that bend sharply and lie along the surface of the leaf.

(4) *Hairs* in great variety are developed upon leaf surfaces, being outgrowths from the epidermal cells. They may form only a slightly downy covering (Fig. 21), or the leaf may be covered by a woolly or felt-like mass so that the epidermis is entirely concealed, as in the common mullein (Fig. 22). In dry or cold regions the hairy covering of leaves is very noticeable, often giving them a brilliant silky white or bronze look. Sometimes instead of hairs the epidermis develops scales of various patterns (Fig. 23), often overlapping and forming a complete covering. The great variety of these hairs and scales, and the ease with which they may be examined, make them an attractive study. At the same time, just how they protect the leaves is by no means

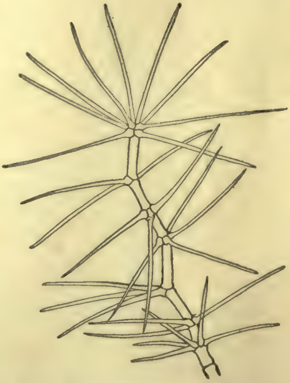

FIG. 22.—Branching hair of mullein.

clear; and doubtless they may serve other purposes also, or sometimes may even be of no use whatever to the plant. It has been suggested that in regions of intense light a covering of hairs is an effective sun-screen. The explanation is that being dead structures, containing air, they reflect the light, thus diminishing the amount that reaches the working cells. As is well known, hairs are by no means restricted to leaves, but occur on all parts of plants.

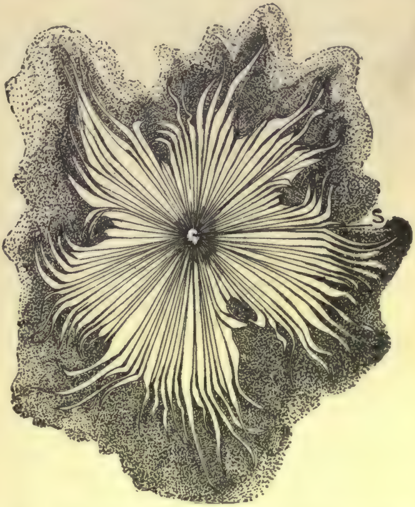

FIG. 23.—Scale from the leaf of *Shepherdia;* such scales overlap and form a complete covering.

(5) *Small leaves* are characteristic of dry regions, in this way each leaf exposing a small surface to the drying air and intense light. That this reduction in size holds a direct relation to the dry conditions is evident from the fact that the same plant often produces small leaves in a dry region and larger ones in moist conditions. In the case of the cactus, a large group in the dry regions of the Southwest, the leaves have become so much reduced that they are no longer used in photosyn-

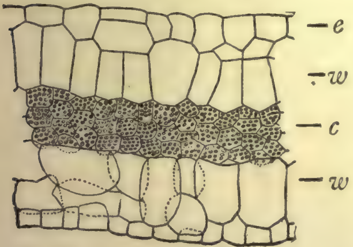

FIG. 24.—Section through a leaf of *Begonia*, showing epidermal layers (*e*), colorless water storage tissue (*w*), and the central cells containing chloroplasts (*c*).

thesis, and this process is carried on by the green tissue of the globular, cylindrical, or flattened stems (Fig. 25).

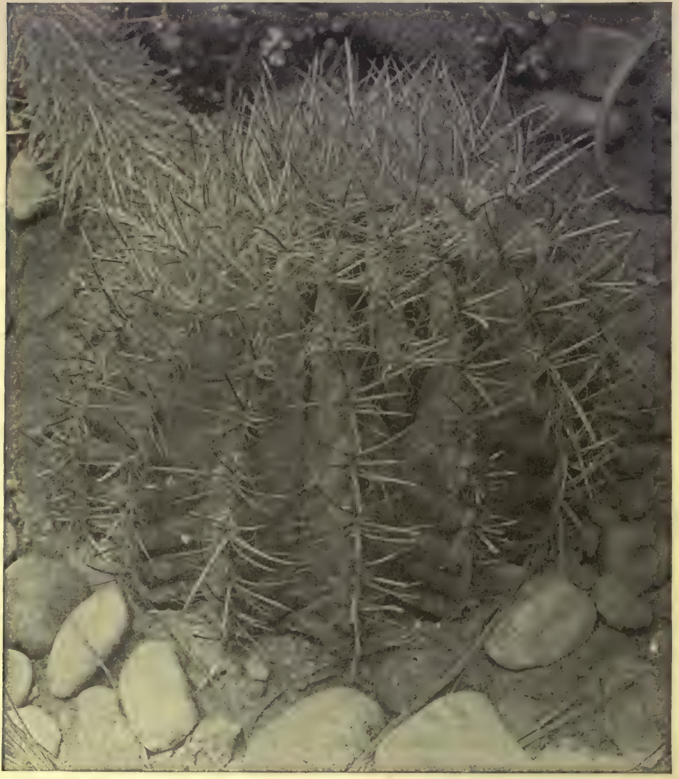

FIG. 25.—A globular cactus, with ribbed stem bearing spines and no foliage leaves.

(6) The *rosette-habit* (§ 12) is a very common method of protection used by small plants growing in exposed situations, as bare rocks and sandy ground. The clustered leaves, flat upon the ground or nearly so, and more or less overlapping, form a very effective arrangement for resisting intense light or drought (Figs. 6 and 7).

(7) *Water reservoirs* are common in leaves and other parts of plants of dry regions, and while they may not be regarded as a protection against loss of water, they accomplish the same purpose in storing it. Usually the water reservoir is a definite tissue, and in many leaves it may be distinguished from the ordinary green working cells by being a group of colorless cells (Fig. 24). In plants of the drier regions leaves may become thick and fleshy through acting as water reservoirs, as in the agave. In the cactus the peculiar stems have become great reservoirs of moisture. The globular body may be taken to represent the form of body by which the least amount of surface may be exposed and the greatest amount of water storage secured (Fig. 25). In the case of these fleshy leaves and fleshy bodies it has long been noticed that they not only contain water, but also have great power of retaining it. Plant collectors have found much difficulty in drying these fleshy forms, some of which seem to be able to retain their moisture indefinitely, even in the driest conditions.

(8) *Profile leaves* are those in which the margin is directed upward, in this way standing edgewise. This position is developed in connection with intense light, and results in turning away the flat faces of the leaves from the intense rays of midday and exposing them to the morning and evening rays of less intensity. In the dry regions of Australia the leaves of many of the forest trees and shrubs have this characteristic edgewise position, giving to the foliage a peculiar appearance. The most famous illustration in this country of a plant with profile leaves is the so-called compass plant, a rosinweed of the prairie region. Its name was given because its leaves were said to point north and south, serving the purpose of a compass. It is evident that the plane of a profile leaf, exposing its faces to the morning and evening sun, will lie in a general north and south direction. It is a significant fact that when

such a plant grows in the shade the leaves do not assume the profile position. It must not be supposed that there is any accuracy in the north or south direction, as the edgewise position is the significant one. In the rosinweed probably the north and south direction is the prevailing one; but in the prickly lettuce, a very common weed of waste grounds, and one of the most striking of the compass plants, the edgewise position is frequently assumed without any reference to the north or south direction of the apex (Fig. 26).

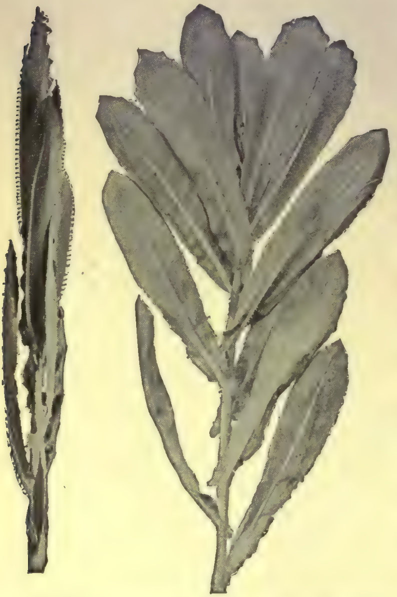

FIG. 26.—Prickly lettuce, showing the edgewise or profile leaves from two points of view.

(9) *Motile leaves* have the power of shifting their positions according to their needs, directing their flat surfaces toward the light, or more or less inclining them. Such leaves have been developed most extensively in the great family to which peas and beans belong, the most conspicuous ones being those of the so-called sensitive plants. The name has been given because the leaves respond to various external influences by changing position with remarkable rapidity. A slight touch, or even jarring, will call forth a response from the leaves; and the sudden application of heat gives striking results (Fig. 27). The most common sensitive plant abounds in dry regions, and may be taken as a type of such plants. The leaves are divided

into very numerous small leaflets, sometimes very small, which stretch in pairs along the leaf branches. When a drought begins, some pairs of leaflets fold together, slightly reducing the surface exposure. If the drought continues, more leaflets fold together, then still others, until finally all the leaflets may be folded together, and the leaves themselves may bend against the stem. In this way the exposed surface may be regulated according to the need.

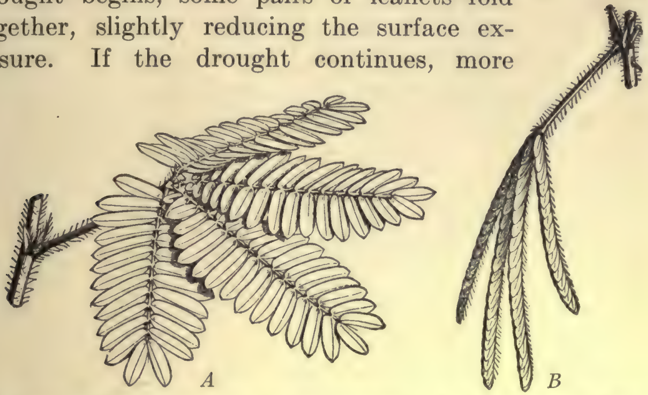

Fig. 27.—Leaf of sensitive plant in two conditions: *A*, fully expanded, with the four main branches and numerous leaflets well spread; *B*, after a shock of some kind, the leaflets being thrown together forward and upward, the four branches having been moved toward each other, and the main petiole having dropped sharply downward.—After Duchartre.

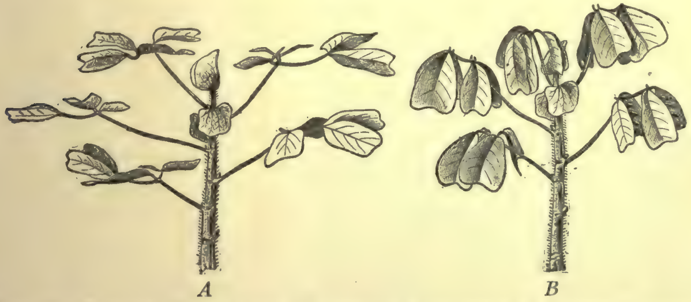

Fig. 28.—The day (*A*) and night (*B*) positions of the leaves of a clover-like plant. —After Strasburger.

Motile leaves also shift their positions throughout the day in reference to light; and at night a very characteristic position is assumed, once called a sleeping position, but better night position. The contrast between the day and night positions of leaves such as those of the sensitive plants, and even of the common white clover, is quite striking (Fig. 28). These night positions, produced by the withdrawal of light, may be induced by placing plants in darkness; and experiments will show that the power is more common than is generally supposed. Just what it means is not clear. The suggestion has been made that the night position is a protection against danger from the loss of heat, but it may have no such meaning.

(10) *Rain* is a menace to leaves, for if the water soaks in and fills up the air spaces and stomata, communication with the air is cut off; hence leaves shed water with remarkable promptness, partly by their positions, partly by their structure. Some of the structures that prevent the rain from soaking in are a smooth epidermis, a cuticle, a waxy deposit, felt-like coverings, overlapping scales, etc. In the rainy tropics it is very common for the sunken veins and ribs of the leaves to form a sort of drainage system for carrying off water, the main channel lying along the midrib, which terminates in a long, spout-like point (Fig. 319).

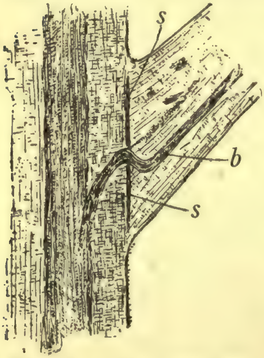

FIG. 29. — Diagrammatic section through a node of horse-chestnut, showing the position of the cutting-off layer (*s*) and the vascular bundle (*b*) not cut through.

18. **Fall of leaves.**—Many shrubs and trees of temperate regions lose their leaves at the approach of winter, or even earlier, putting out new leaves in the following spring. This is called the *deciduous habit*, and it is an adaptation to climate. While

in some deciduous leaves, as those of oaks, there is no special preparation for falling, in most of them a special plate of cells is formed at or near the juncture of the leaf with the stem, known as the cutting-off layer, which gradually loosens the leaf from the stem, so that it falls by its own weight or is wrenched off by the wind (Fig. 29).

In connection with the deciduous habit there often appears the autumn coloration of leaves, so striking a feature of temperate forests. The colors that appear are shades of yellow and red, either pure or variously intermixed. They are the result of the waning activity of the leaf, the yellow mostly being the color of the dying chloroplast, and the red coming from the presence of a new substance manufactured in the enfeebled cells. The popular belief that these colors are caused by frost is only partly true, for they often appear before any frost; but they may be induced by any conditions that tend to diminish the activity of the leaf, and cold is one of the conspicuous conditions.

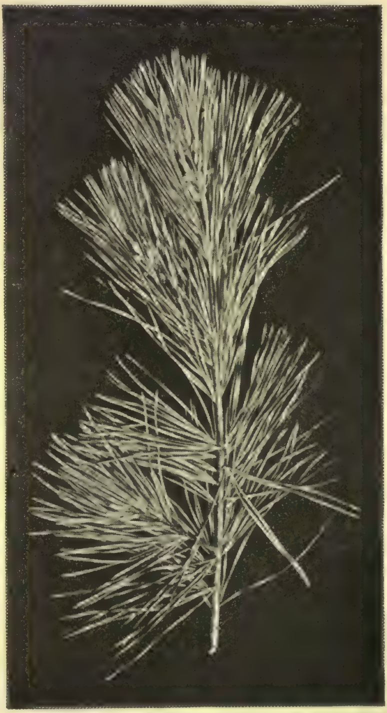

FIG. 30.—The needle-leaves of a pine.

19. **Leaves of evergreens.**—In contrast with the deciduous shrubs and trees are the so-called *evergreens*, in which

there is no regular annual fall of leaves. Such leaves endure for a varying length of time; but as there is no regular period for all of them, the shrub or tree always appears in foliage. In the temperate regions the most conspicuous evergreens are the pines and their allies. A comparison between the needle-leaf of a pine and the leaf of an ordinary deciduous tree will show what the evergreen habit involves in temperate regions (Fig. 30). The leaf of a pine must be protected so as to endure the winter, and this has involved reduction of surface and extremely thick protective layers about the mesophyll (Fig. 31). This has diminished the ability to work; but it has saved the tree the necessity of putting out a complete new crop of leaves for the next season. The deciduous leaf, on the other hand, is broad and thin, with great capacity for work; but this forbids protection during the winter.

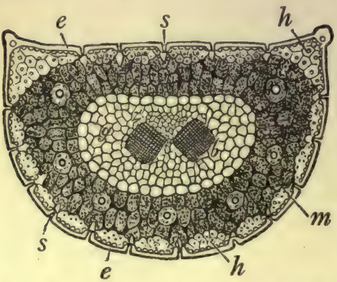

FIG. 31.—Cross-section of the needle-leaf of a pine, showing the epidermis with heavy cuticle (*e*), in which are sunken stomata (*s*); masses of heavy-walled cells (*h*) beneath the epidermis; the mesophyll region (*m*) containing chloroplasts, and the central colorless region containing two vascular bundles.—After SACHS.

20. **Special forms of leaves.**—Besides the ordinary leaves that have been considered, and which are called in distinction *foliage leaves*, there are special forms of leaves whose chief work is different. In so far as they are green, they manufacture carbohydrates as do the foliage leaves, but a distinct change in structure and behavior indicates that this is not their chief work.

(1) *Scales.*—The most conspicuous illustrations of leaves that have become modified into *scales* are to be found in subterranean stems and scaly buds. Underground stems cannot produce foliage leaves on account of the absence of

light, but they produce leaves reduced in size and without green tissue. Often these scales seem to be merely useless relics (Fig. 64); but sometimes they are used for food storage, as in lily bulbs, onions, etc., which are mostly made up of fleshy scales (Fig. 65).

In the scaly buds, so common on shrubs and trees, the overlapping scales are clearly protective structures, and to this end are generally firm and resistant, often coated with resin, the inner ones being frequently clothed with woolly hairs.

(2) *Tendrils.*—The whole leaf or some of its branches may develop as tendrils, the latter case being illustrated by the sweet pea (Fig. 32). Tendrils are sensitive to contact and aid in climbing. Sometimes leaves act as tendrils without any modification of the blade, the petiole being sensitive to contact and encircling supports like a tendril, as in the garden nasturtium.

(3) *Thorns.*—Leaves developing as thorns may be observed in the barberry (Fig. 33). In the common locust, acacia, etc., only the stipules develop as thorns.

Both tendrils and thorns are also developed as stem structures, being modified branches.

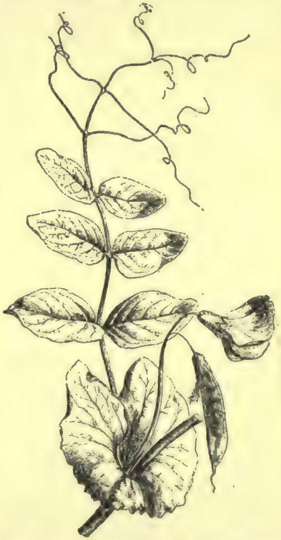

FIG. 32.—Pinnately compound leaf of garden pea, whose terminal portion has developed as tendrils. — After STRASBURGER.

(4) *Leaves of pitcher-plants.*—In these plants the leaves form tubes or urns of various forms, which contain water; and to these insects are attracted and drowned. The common pitcher-plant of the northern States, a *Sarracenia,* is a well-known

bog plant (Fig. 34), but is not so elaborately constructed for capturing insects as is a common southern *Sarracenia* (Fig. 35). In this plant the leaves are slender, hollow cones, and rise in a tuft from the swampy ground. The mouth of this conical urn is overarched and shaded by a hood, in which are translucent spots, like numerous small windows. Around the mouth of the urn are glands which secrete a sweet liquid, known as *nectar.* Inside, just below the rim of the urn, is a glazed zone, so smooth that insects cannot walk upon it. Below the glazed zone is another one thickly set with stiff, downward-pointing hairs; and below this is the liquid in the bottom of the urn. If a fly, attracted to the nectar at the rim of the urn, attempts to descend within the urn, it slips on the glazed zone and falls into the water; and if it attempts to escape by crawling, the downward-pointing hairs prevent. If it seeks to fly from the rim, it naturally flies toward the translucent spots in the hood, since the direction of entrance is in the shadow; and pounding against the hood,

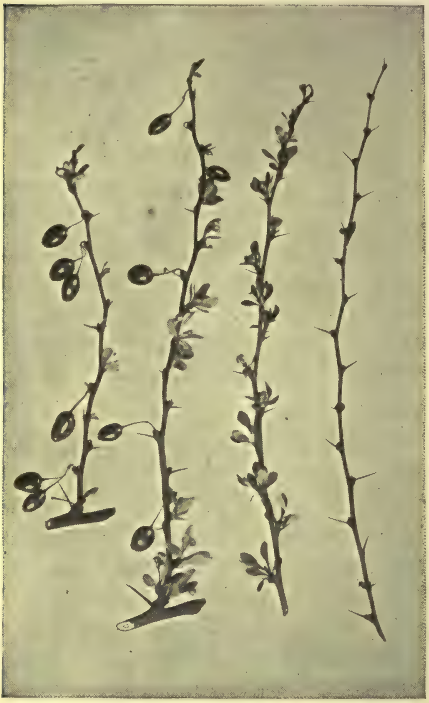

FIG. 33.—Leaves of barberry developing as thorns.

the fly usually falls into the tube. The pitchers generally contain the decaying bodies of numerous drowned insects.

A much larger Californian pitcher-plant is *Darlingtonia* (Fig. 36), whose leaves are one and a half to three feet high, the hood bearing a gaudily colored "fish-tail" appendage, the whole structure being a more elaborate insect trap than are the leaves of *Sarracenia*. In these traps not only are the remains of flies found, but bees, hornets, butterflies, beetles, grasshoppers, and even snails have been reported.

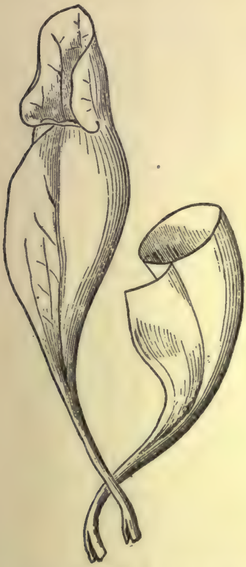

Fig. 34.—Leaves of the common northern pitcher-plant, one of them sectioned to show cavity and wing.—After Gray.

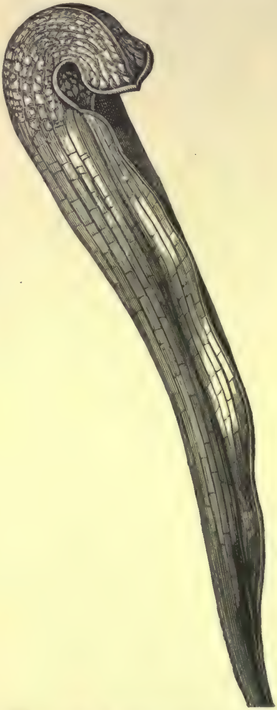

Fig. 35.—Leaf of a southern pitcher-plant, showing the funnelform and winged pitcher, and the overarching hood with translucent spots.—After Kerner.

The species of *Nepenthes* from the oriental tropics, very common in conservatories, develop most remarkable leaves, the lowest part being an ordinary blade, beyond which is a well-developed tendril, at the end of which there arises an elaborate pitcher with a lid (Fig. 37). There is the same sweetish secretion at the rim of the pitcher, and the same accumulation of water within as in the ordinary pitcher-plants.

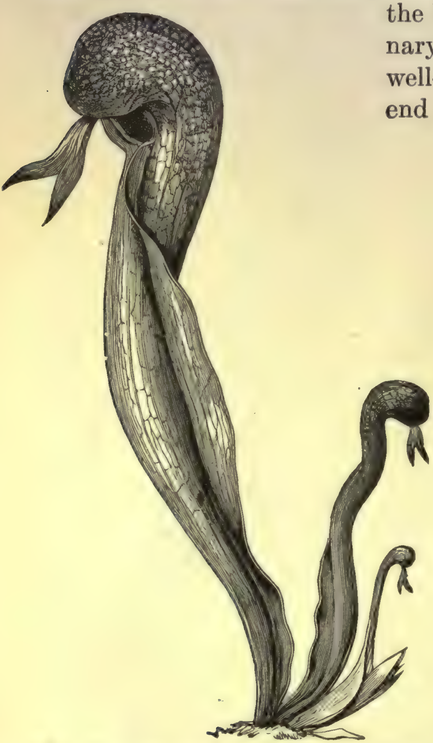

Fig. 36.—Leaves of the Californian pitcher-plant, showing the twisted and winged pitcher, the overarching hood with translucent spots, and the fish-tail appendage to the hood.—After Kerner.

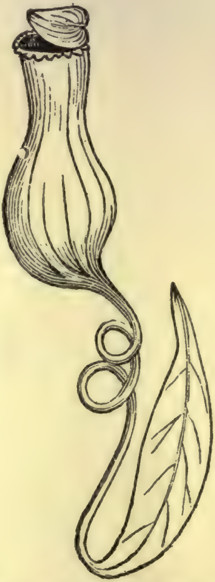

Fig. 37.—Leaf of *Nepenthes*, showing the blade-like base, the tendril portion, and the terminal pitcher with its lid.—After Gray.

(5) *Leaves of sundews.*—The sundews are forms of *Drosera* and grow in swampy regions, the leaves forming

small rosettes upon the ground (Fig. 38). In one form the blade is round, and the margin is beset by prominent bristle-like hairs, each with a globular gland at its tip (Fig. 39). Shorter gland-bearing hairs are scattered also over the inner surface of the blade. All these glands excrete a clear, sticky fluid, which hangs to them like dewdrops, and which, not being dissipated by sunlight, has suggested the name sundew. If a small insect becomes entangled in

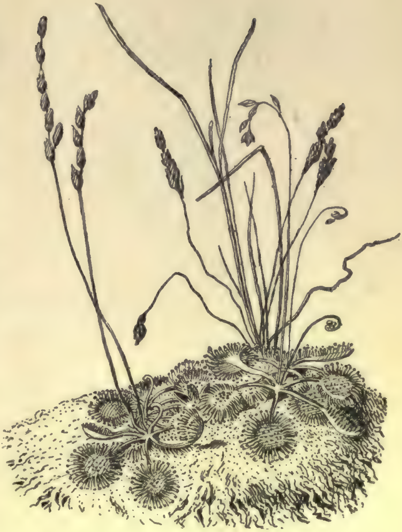

Fig. 38.—Sundews.—After Kerner.

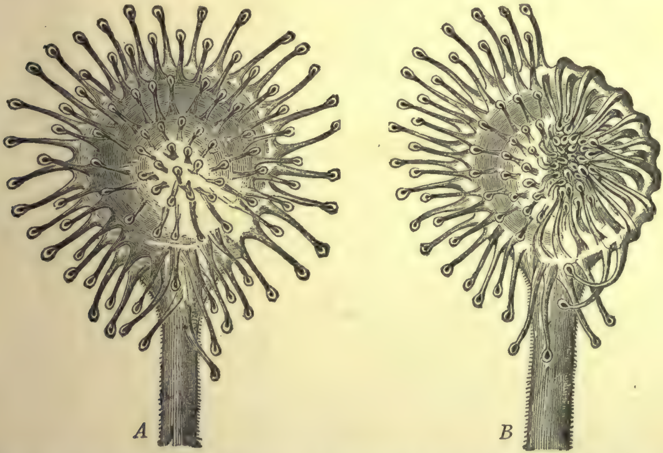

Fig. 39.—Two leaves of a sundew: *A*, glandular hairs fully extended; *B*, half the hairs bending inward, in the position assumed when an insect has been captured.—After Kerner.

one of the sticky drops, the hair begins to curve inward, and presently presses its victim down upon the surface of the blade. In the case of a larger insect, several of the marginal hairs may join together in holding it, or the whole blade may become more or less rolled inward.

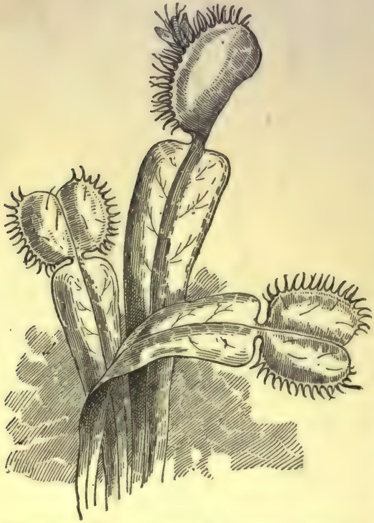

FIG. 40.—Three leaves of *Dionœa:* two with the traps open, one with trap shut on an insect.—After KERNER.

(6) *Leaves of Dionœa.*—This is one of the most famous and remarkable of insect-trapping plants, being found only in certain sandy swamps near Wilmington, N. C. The leaf-blade is constructed so as to work like a steel trap, the two halves snapping together, and the marginal bristles interlocking like the teeth of a trap (Fig. 40). A few sensitive hairs, like feelers, are developed on the leaf surface; and when one of these is touched by a small flying or hovering insect, the trap snaps shut and the insect is caught. Only after digestion, which is a slow process, does the trap open again. *Dionœa* is popularly known as the "Venus fly-trap."

Sarracenia, Drosera, and *Dionœa* are conspicuous representatives of the so-called carnivorous or insectivorous plants, all of which capture insects and use them for food. They are green plants, so that they manufacture carbohydrates; but for some reason they supplement their food manufacture with a supply of food already manufactured, and obtained from the bodies of captured insects.

CHAPTER III

STEMS

21. **Relation to other organs.**—The stem is connected with the roots and bears the leaves. So constant a feature of the stem is leaf-bearing that the presence of leaves is one method of distinguishing underground stems from roots. Not merely do stems bear leaves, but they usually bear them in such a way as to expose them well to the air and the sunlight. Often stems branch, and in this way increase their power of producing and displaying leaves. It is evident that the stem, more than anything else, is the leaf-bearing organ; and in bearing leaves it must be also the channel of communication between them and the roots.

So closely associated are stems and leaves that they are spoken of together as the *shoot;* and thus the whole body of the plant of ordinary experience is said to consist of shoot and root, the former usually exposed to the air (aerial), the latter usually exposed to the soil (subterranean). As any branch is merely a repetition of the stem from which it arises, so any branch with its leaves is a shoot, just as the whole stem system with its leaves is a shoot.

22. **External structure.**—The ordinary stem is a jointed structure. While this is very evident in such stems as the corn-stalk and the cane (seen in fishing-rods), it is often made apparent only by the leaves, which appear at the joints or *nodes* (§ 8). The portions of the stem between the nodes—portions which do not bear leaves—are the *internodes;* hence a stem is a series of alternating nodes and internodes.

Branches as well as leaves appear at the nodes; and there is usually a very definite relation between them, the branch appearing in the upper angle between leaf and stem, called the *axil* of the leaf (Fig. 41). Most branches are thus *axillary* in position. The internodes give length to the stem, separating the nodes from each other, and so displaying the leaves more freely to the air and the sunlight.

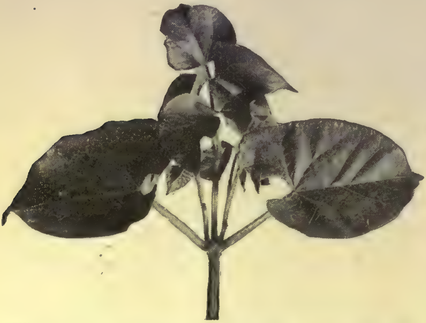
Fig. 41.—A scarlet runner bean, showing leaf-bearing nodes, internodes, and axillary branches.

23. **Direction of stems.**—The directions in which stems grow are due to a variety of causes, some of which will be considered later; but for the present only certain positions will be noted.

(1) *Erect stems.*—The upright stem is the most common; and it seems altogether the best adapted for the proper display of leaves, for they can be spread out on all sides and carried upward toward the light. To maintain the erect position is not a simple mechanical problem, and in large woody stems it involves an extensive development and arrangement of supporting tissues. That some special organization is necessary to maintain the erect position in the air is evident when aerial erect stems are contrasted with submerged erect stems. In small lakes and slow-moving streams submerged plants are commonly seen, as the pickerel-weed and numerous others. In the water the stems are erect; but when taken out they collapse, having been sustained in position by the water.

Among aerial stems the tree is the most impressive, and it has developed into a great variety of forms or habits. In some trees, as the pines and their allies, the main stem continues as a central shaft to the top, the branches spreading horizontally from it (Fig. 42); while in other trees, as the oak and the elm (Figs. 43 and 44), the main stem soon divides into large branches. In the former case the

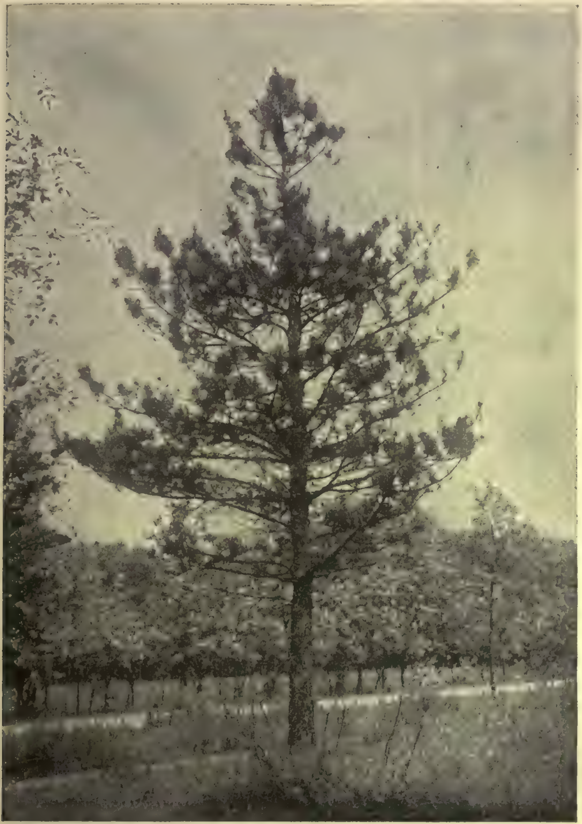

FIG. 42.—An Austrian pine.

tree has a general conical outline; in the latter case it has a spreading top or crown. It is an excellent plan to become acquainted with the common trees of a neighborhood and to learn to recognize them by their habits. Trees are also an excellent illustration of the fact that while the main stem of a plant may be erect, the branches may be di-

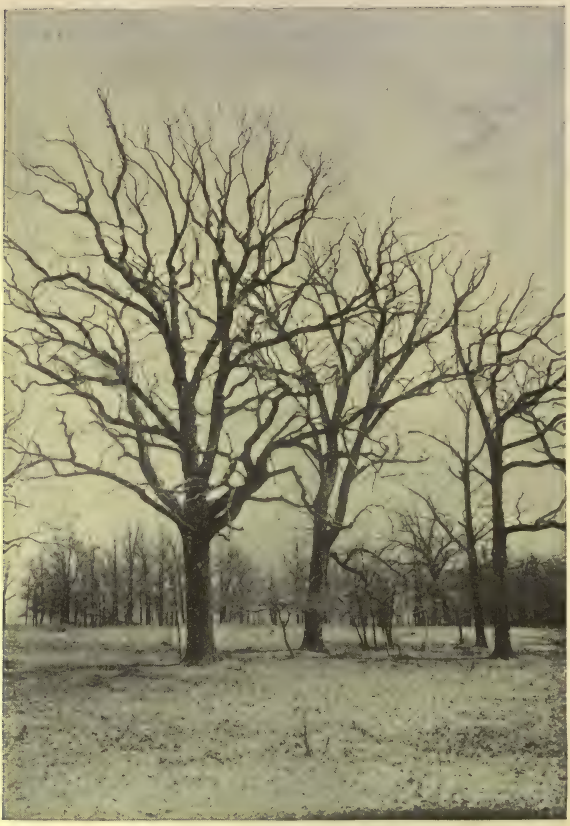

Fig. 43.—An oak in winter condition.

rected at any angle, often horizontal, and sometimes even descending.

(2) *Prostrate stems.*—In many plants the main stem or certain branches lie prostrate on the ground or nearly so, sometimes spreading in all directions and becoming interwoven into a mat or carpet (Fig. 45). They are found

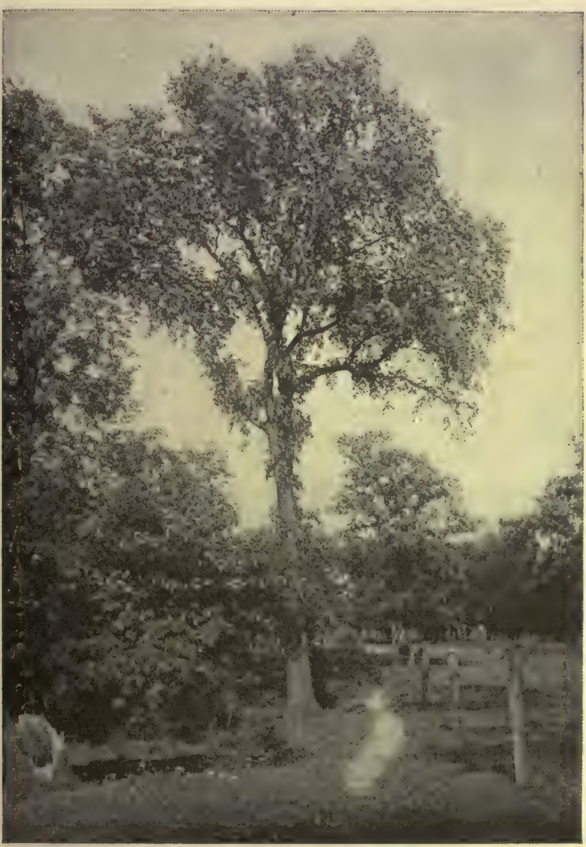

Fig. 44.—An elm in foliage.

especially on sterile and exposed soil, and there may be an important relation between this fact and their habit. In such stems there is a distinct disadvantage in the display of leaves as compared with erect stems; for instead of being free to spread out leaves on all sides, one side is against the ground, and the free space for them is diminished at least one-half. All the leaves such a stem bears are necessarily directed toward the free side.

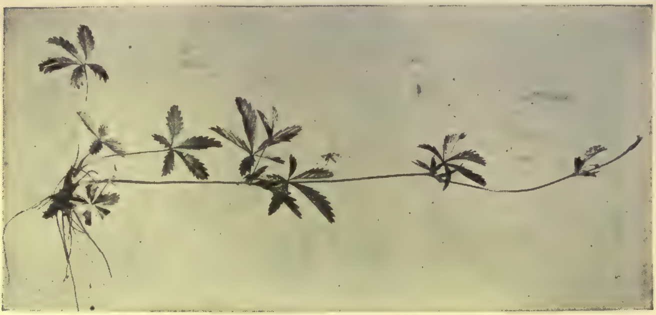

FIG. 45.—Prostrate stem of *Potentilla*.

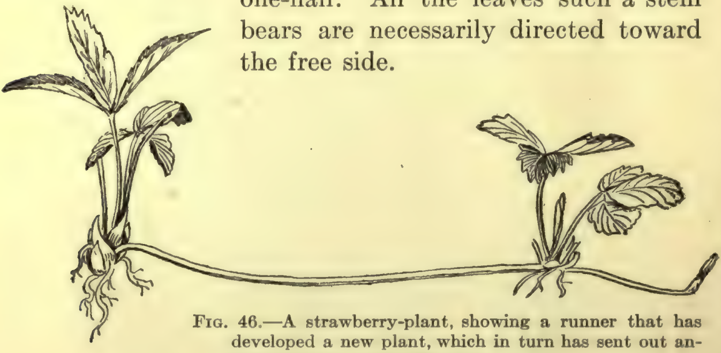

FIG. 46.—A strawberry-plant, showing a runner that has developed a new plant, which in turn has sent out another runner.—After SEUBERT.

We may not know all the reasons why so unfavorable a position for leaf display is assumed; but among the results are protection in exposed situations in some cases, and the multiplication of plants in others. In many plants, as the prostrate stem advances over the ground, roots develop from the nodes and enter the soil, leaves are formed, and a new plant is started, which may become independent by the death of the older parts. In this way a plant may spread over the ground, multiplying itself indefinitely. So effective is this method of multiplication that plants with erect stems often make use of it, sending out from near the base special prostrate branches which advance over the ground and start new plants. A very familiar illustration is furnished by the strawberry-plant, which sends out peculiar leafless runners to strike root at the tip and start new plants, which become independent by the death of the runners (Fig. 46).

These various prostrate stems illustrate the fact that nodes can produce not only leaves and branches, but also roots, if placed in suitable conditions. Advantage is taken of this fact in the common process of layering, in which such stems as those of blackberries and raspberries are bent down to the ground and covered with soil, when the nodes strike root and new plants are started.

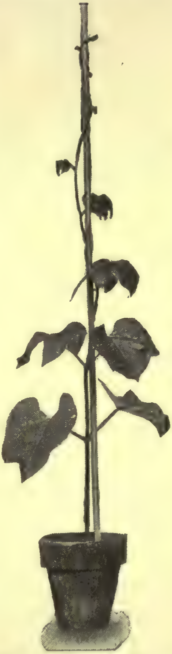
FIG. 47.—A bean twining about a support.

(3) *Climbing stems.*—A great many plants have developed the ability to sustain themselves by using supports. Although not able to stand alone, by using these supports they may attain great length and display their leaves to light even in a dense forest. This climbing is effected in a variety of ways. In some cases, as the morning-glory, bean, and hop-vine, the stem twines about the support, such plants often being distinguished as twiners (Fig. 47);

in other cases, as the grape-vine and star-cucumber, tendrils are formed, which twine or hook about the supports (Fig. 48); in still other cases, as the woodbine, the tendrils produce suckers that act as holdfasts and enable the plant to cling to trees or walls (Figs. 49 and 50). It is in the dense forests of the tropics that climbing plants become especially conspicuous. There great woody vines fairly interlace the vegetation, and are known as *lianas* or *lianes*.

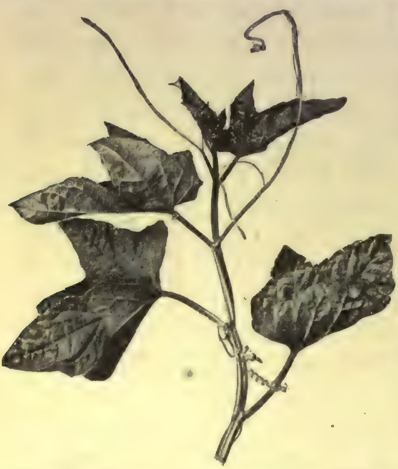

Fig. 48.—Branch of star-cucumber, with its tendrils in various conditions.

If a young morning-glory or twining bean be watched, it will be discovered that the elongating stem is unable to stand upright, and that, as it bends over, the inclined part begins to swing through a horizontal curve, which may bring the stem in contact with a suitable support. If this happens, the stem, continuing to swing in a curve and growing in length at the same time, winds itself about the support. This movement of the portion of the stem which is in a horizontal position is thought to be brought about by a peculiar response of the plant to gravity. The influence of gravity in directing plant organs will be considered later.

Tendrils are illustrations of plant structures that are unusually sensitive to contact. When the tip of a tendril in moving about touches a suitable support, the side touched becomes concave and the tendril hooks or coils about the support. This is only the first response of the tendril to contact, for presently the rest of it begins to curve—a move-

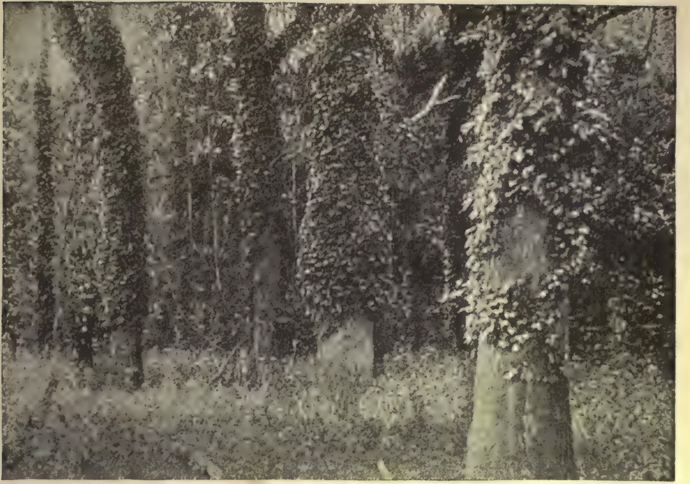

FIG. 49.—Woodbine in a deciduous forest.

ment which results in spiral coils, since the tendril is fastened at both ends (Fig. 48). This curving and twisting of the tendril between its fastened extremities naturally results in two spiral coils running in opposite directions. In this way the stem is fastened to its support by numerous spiral springs. All of these movements and their results may be observed by cultivating a plant such as the star-cucumber, which grows rapidly and has conspicuous and very sensitive tendrils. In the case of the ordinary climbing woodbine and certain species of ivy, which cling to walls or tree

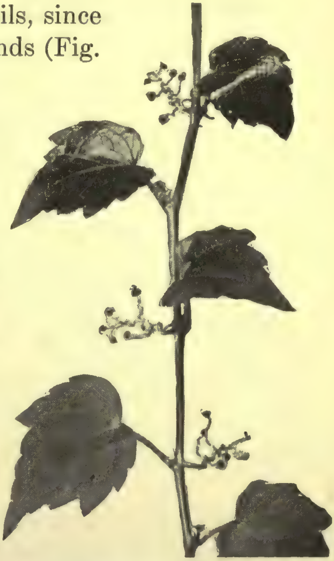

FIG. 50.—Woodbine clinging to a wall by means of tendril suckers.

trunks, the tip of the tendril when it comes into contact with a support is stimulated into developing the sucker-like disk which acts as a holdfast (Fig. 50).

24. **Internal structure.**—As the stems of seed-plants show two distinct types of structure, it will be necessary to point out the great groups of seed-plants, so that the types of structure may be referred to them. The *Gymnosperms* include the pines and their allies, the common evergreens; the *Monocotyledons* include such plants as grasses, lilies, and palms; the *Dicotyledons*, much the largest group, include the common deciduous trees, such as oak, maple, hickory, poplar, beech, etc., as well as the great majority of common herbs. In stem structure the Gymnosperms and the Dicotyledons show the same general plan, while the other type of structure is exhibited by the Monocotyledons.

(1) *Gymnosperms and Dicotyledons.*—If an active twig of an ordinary woody plant be cut across, it will be seen that it is made up of four general regions (Fig. 51): (1) an outer protecting layer which may be stripped off as a thin skin, the *epidermis;* (2) within this a zone of spongy tissue, usually green, the *cortex;* (3) then a relatively broad zone of firm wood, the *vascular cylinder;* and (4) in the center the *pith.* The special feature of this arrangement is that the wood occurs as a hollow cylinder, enclosing the pith and surrounded by the cortex. In the older parts of stems the pith often disappears, leaving a hollow stem. The cortex is the active,

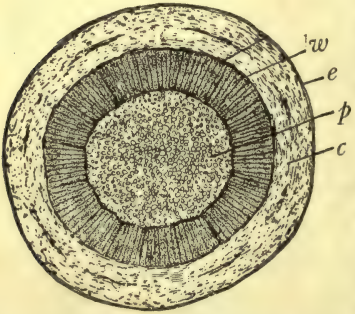

FIG. 51.—Cross-section of a branch of box elder one year old: *e*, epidermis; *c*, cortex; *w*, vascular cylinder; *p*, pith.

working region of the stem: since it is green it is able to manufacture carbohydrates as do the leaves (§ 14); and it is also concerned in other work connected with nutrition. The vascular cylinder, on the other hand, is the great conducting region, as well as one that gives rigidity to the stem. This work of conduction will be considered later.

If the vascular cylinder be examined closely, it will be seen that it is broken up into segments by plates of cells that traverse it from the pith to the cortex, these radiating plates of cells being the *pith rays* (Fig. 51). The cylinder is thus made up of a number of segments which are called *vascular bundles.* The peculiarity of the structure of the stem in Gymnosperms and Dicotyledons, therefore, can be described as the arrangement of the vascular bundles so as to form a hollow cylinder. In woody stems the bundles are very close together in the cylinder, forming a compact cylinder with narrow pith rays; but in the stems of herbs the bundles are well separated, leaving broad pith rays.

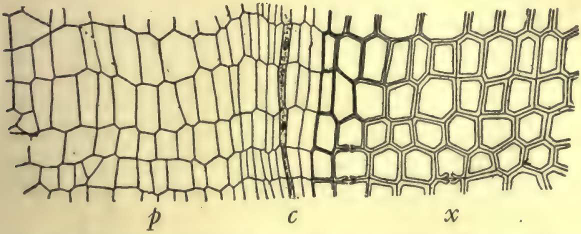

Fig. 52.—Cross-section of vascular bundle from pine stem, showing xylem (*x*), cambium (*c*), and phloem (*p*); on each side of the single row of cambium cells there are young xylem and phloem cells that pass gradually into the mature condition.

If the cross-section of an individual vascular bundle be examined under the microscope, two regions will be recognized (Fig. 52): the inner one, toward the pith, being called *wood* (*xylem*), and the outer one being called *bast* (*phloem*).* A vascular bundle, therefore, is made up of wood and bast, which differ from one another in the work of conduction, the wood chiefly conducting the water that enters the plants by the roots and is passing to the leaves, and the bast chiefly conducting prepared food.

The cells of the wood that conduct water are called *tracheary vessels.* They are more or less elongated and have very thick walls, upon which there appear markings of various kinds. These markings may be seen in a longitudinal section through the wood. Some of the vessels are marked by a spiral band that extends from end to end, and are called *spiral vessels* (Fig. 53, *A*); others show a series of thickened rings, and are called *annular vessels* (Fig. 53, *B*); while others, and among them the largest,

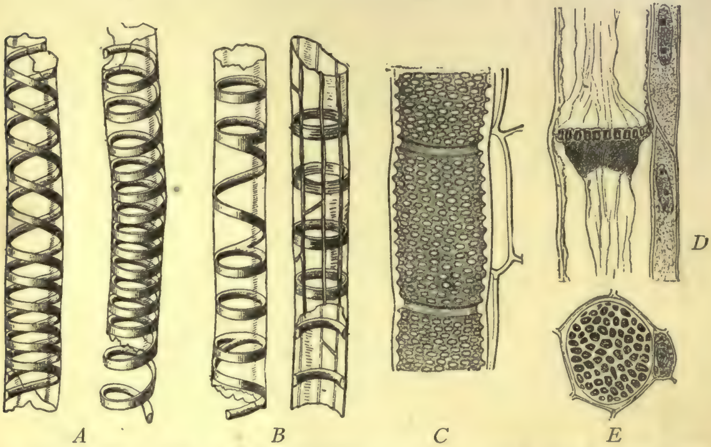

FIG. 53.—Vessels: spiral (*A*) and annular (*B*) vessels; dotted vessel (*C*); sieve vessel (*D*) and sieve plate (*E*) from pumpkin.—*A* and *B* after BONNIER and SABLON; *C* after DE BARY; *D* after STRASBURGER.

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* If a cross-section of a pine twig be stained first with safranin and afterward with Delafield's hæmatoxylon, the xylem will become bright red and the phloem rich violet.

have numerous thin spots in their walls which look like dots of various sizes, and these are the *dotted* or *pitted vessels* (Fig. 53, *C*), often called *dotted ducts*. These pitted vessels are often very large, their openings being visible to the naked eye in the cross-section of oak wood.

The cells of the bast that conduct prepared food are called *sieve vessels* (Fig. 53, *D*), because in their walls, usually the end walls, there appear areas full of perforations, like the lid of a pepper-box, these areas being called *sieve-plates* (Fig. 53, *E*).

The veins of leaves are vascular bundles that are continuous with those of the stem. If the relative positions of wood and bast in the stem be remembered, it will be seen that when a bundle turns out into a leaf, the wood with its tracheary vessels is toward the upper side of the leaf, and the bast with its sieve vessels toward the lower side.

A prominent feature of such stems is that they can increase in diameter. If the stem lasts only one growing season, that is, if it is an *annual*, the increase in diameter does not occur; but if it lasts through several seasons, that is, if it is a *perennial*, it increases in diameter from year to year. Naturally annual stems belong to herbs and perennial stems to shrubs and trees. Taking the tree as an illustration, the increase in diameter occurs as follows: Between the wood and the bast of each bundle is a layer of very active cells called the *cambium* (Fig. 52, *c*), which soon extends across the intervening pith rays, and so forms a complete cylinder of cambium. This cambium has the power of adding new wood cells to the outer surface of the wood, and new bast cells to the inner surface of the bast, as well as adding to the pith rays where it traverses them. In this way a new layer of wood is laid down on the outside of the old wood; and usually these layers, added year after year, are so distinct that a section of wood shows a series of concentric rings (Fig. 54). Ordinarily one such layer is added each year, and hence the layers are called *annual rings.* The age of a tree is usually estimated by counting these rings, but occasionally more than one ring may be added during a single year. The new layers added to the bast are not persistent; but the wood accumulates year after year, until in an ordinary tree the stem is a great mass of wood covered with thin layers of bast and cortex. It is this mass of wood that supplies our lumber.

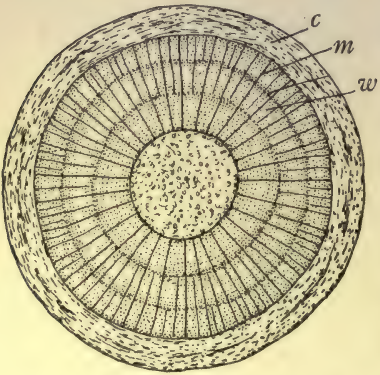

FIG. 54.—Cross-section of a branch of box elder three years old, showing three annual rings in the vascular cylinder; the radiating lines (*m*) which cross the vascular ring (*w*) represent the pith rays, the principal ones extending from pith to cortex (*c*).

This annual increase in diameter enables the tree to put out an increased number of branches, and hence leaves, each succeeding year, so that its capacity for leaf work becomes greater year after year. A reason for this is that since the wood is conducting water to the leaves, for food manufacture, the new layers enable it to conduct more water, and more leaves can be supplied.

When a stem increases in diameter it is very seldom that the epidermis grows in proportion. Hence it is usually sloughed off and a new protective covering is developed by the cortex. Either the outermost layer of the cortex or some deeper one becomes a cambium, which means that it is able to form new cells. This cambium is called the *cork cambium,* since it forms at its outer surface layer after layer of cork cells, which are peculiarly resistant to water. If the cork cambium is formed deep in the cortex, all the cells outside of it die, since they are cut off from the water supply in the plant. The cork cambium is often renewed year after year, and two prominent kinds of bark are formed. In some cases the successive cork cambiums form zones completely about the stem, and the cork is then deposited in concentric layers, forming the *ringed bark.* Such bark often becomes very thick, and the surface becomes seamed or furrowed. In the cork oak there is a very great accumulation of cork, which is stripped off in sheets, from which corks of commerce are made. In other cases the successive cork cambiums, instead of passing completely around the stem, run into the next outer one, thus cutting out segments which presently loosen and flake off, forming *scaly bark,* as in hickory, apple, etc.

The layers of cork and other cells that may lie outside of the cork cambium form the *outer bark,* which is dead and dry. The tissues between the cork cambium and the cambium of the vascular cylinder, that is more or less cortex and the bast, form the *inner bark,* which contains some living cells. To remove the outer bark does not injure a tree; but removing the inner bark kills it, because it interrupts the work of conduction carried on by the sieve vessels. In the process known as girdling, not only is the bark cut through, but the young wood is cut into. This interferes with the movement of water up the stem as well as with conduction by the sieve vessels. If a small portion of the bark is removed, the incision extending only to the wood, as in the making of inscriptions on trees, the wound is healed, unless too large, by the growth of tissue from all sides until it is closed over. In this new tissue a cork cambium is developed, and presently there may be no surface indication of the wound. But if the wound has gone deeper and entered the wood, the record of it may always be found in the wood by removing the bark. In this way old inscriptions have often been uncovered.

The well-known operation of *grafting* depends upon the ability of plants to heal wounds. The plant upon which the operation is performed is called the *stock,* and the twig grafted into it the *scion.* An ordinary method, called *cleft-grafting,* is to cut off the stem or a branch of the stock, split the stump, insert into the cleft the wedge-shaped end of the scion, and seal up the wound with wax or clay. The cambiums of the stock and the scion must be put into contact at some point; and hence it is usual to insert a scion in each side of the cleft, since the cambium of the stock is comparatively near the surface (Fig. 55). The cambium of stock and scion unite, the wound heals, and the scion becomes as closely related to the activities of the stock plant as are the ordinary branches. The scions are usually cut in the fall, after the leaves have fallen, are kept through the winter in moist soil or sand, and the grafting is done in the spring. A number of important things are secured by grafting, but chief among them is the perpetuation of useful varieties with certainty and at a great saving of time.

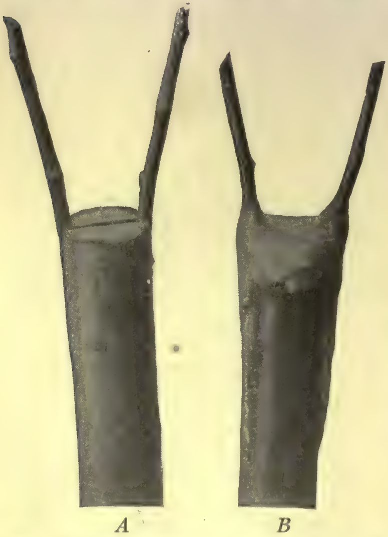

Fig. 55.—Cleft-grafting showing scions in place (*A*) and the wound sealed with clay or wax (*B*).

(2) *Monocotyledons.*—In this great group of plants the vascular bundles of the stem are not arranged so as to form

a hollow cylinder, but are more or less irregularly scattered, as may be seen in a cross-section of a corn-stalk (Fig. 56). As a consequence, there is no enclosing of a definite pith, nor is there any distinctly bounded cortex. In the bundles there is no cambium, and therefore new wood and bast cannot be added to the old, so that in the trees there is no annual increase in diameter; and this means that there is no branching and no increased foliage from year to year. A palm well illustrates this habit, with its columnar, unbranching trunk, and its crown of leaves, which continue about the same in number each year.

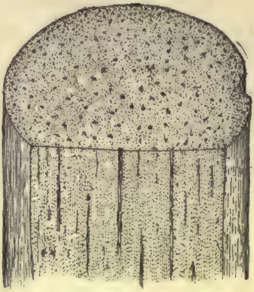

FIG. 56.—A corn-stalk, showing in cross-section and longitudinal section the scattered vascular bundles.

25. **Ascent of sap.**—The water entering the plant by the roots and moving upward through the stem is usually called *sap*. It is not pure water, but contains certain soil substances dissolved in it. In low plants, as most annuals, the ascent of sap requires no special explanation; but in plants such as trees, in which the crown of leaves is many feet above the soil, the case is very different. Several explanations of the ascent of sap in trees have been suggested, and all have been disproved, so that we are as yet entirely in the dark as to the method.

That the path of ascent is through the vessels of the wood, and not through cortex or bast or pith, may be demonstrated by a simple experiment. A stem of corn or sunflower or balsam is cut off and placed in water for an hour. Then it is transferred to a vessel containing water stained with cheap red ink (a solution of eosin), and exposed to diffuse light. A few hours later, sections of the stem will show the wood vessels stained red, the ascending water having stained its path. Of course the stain may spread somewhat into adjacent cells.

In most trees, as the mass of wood increases in diameter, the ascending sap abandons the inner (older) wood and moves only through the newer wood. This results in a different appearance of the two regions, the old central wood, abandoned by the sap, becoming darker and often characteristically colored (*heart wood*); and the younger outer wood, used by the sap, being lighter colored (*sap wood*). Trees vary greatly in the relative thickness of the sap wood; for example, in the beech it is a thick zone, while in the oak it is a narrow one. In successful girdling this must be taken into account, since an incision which would cut off the water supply of an oak sufficiently to kill it would not kill a beech.

The rate of movement of the ascending sap of course varies with different plants and different conditions. In the pumpkin-vine, in which the movement is very rapid, it has been found to reach about twenty feet an hour. It is estimated that in ordinary broad-leaved trees the rate is probably three to six feet an hour.

If certain stems are cut off near the ground, it is observed that after a short time the sap begins to ooze out—a phenomenon that is often called bleeding. In some woody plants, as grape-vines and birches, the sap flows out with considerable force, indicating some pressure below, which is called *root-pressure.* While root-pressure may force the sap into the stem, it is entirely inadequate to force it to the top of a tree.

The so-called maple sap obtained from the sugar-maple is an interesting illustration of the use of sap that accumulates in a woody stem in the spring. At that time the water has no opportunity to escape through leaf transpiration; so the wood becomes gorged with sap, which can be drawn off by boring into the wood and inserting spiles.

The characteristic sugar has been obtained by the sap from food stored in the stem, notably in the older wood.

26. **Growth in length.**—Growth in length begins at the tip of the stem by the formation of new cells, which are organized into alternating nodes and internodes. When these regions are first formed the internodes are very short, and their subsequent elongation, separating the nodes, is the chief cause of the lengthening of the stem. Internodes are able to elongate for only a certain time, so that the elongating portion of a stem does not often extend more than ten to twenty inches below the tip. Seedlings such as those of the bean should be cultivated, and the region of growth, the region of greatest growth, and the rate of growth determined. The same method may be used as was used with the leaf (§ 16), in this case each internode being marked with equally spaced lines in India ink. Measuring these spaces at intervals of one or two days will determine the facts referred to above (Fig. 57).

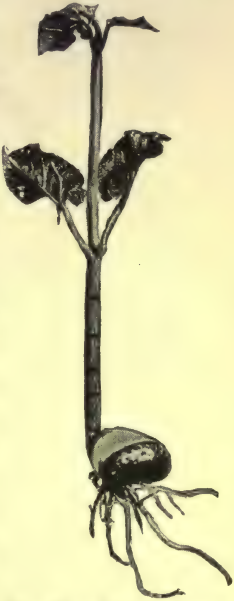

FIG. 57.—Scarlet runner bean marked with a scale of five millimeter intervals and photographed after forty-eight hours; the lines closest together show the original spacing.

27. **Special forms of stems.**—Usually branches resemble the stem from which they arise, but occasionally they differ in a striking way. That these different structures are really branches is usually evident to external observation from the fact that they stand in the position of branches, that is, in the axils of leaves (§ 22). The three following forms illustrate axillary structures that do not resemble ordinary branches.

(1) *Cladophylls.*—If the greenhouse smilax, often called wedding smilax, be examined, the apparent leaves will be discovered to be branches modified so as to assume the form and work of leaves, each one of these leaf-like branches standing in the axil of a minute scale-like leaf (Fig. 58, *A*). Such branches are called *cladophylls,* which means "leaf-like branches." In the Australian region a group of evergreens is characterized by bearing cladophylls; and the young plantlet shows the gradual change of true green leaves into little scales, and of branches into cladophylls (Fig. 58, *B*). In the common garden asparagus the apparent slender, needle-like leaves are all cladophylls doing leaf work.

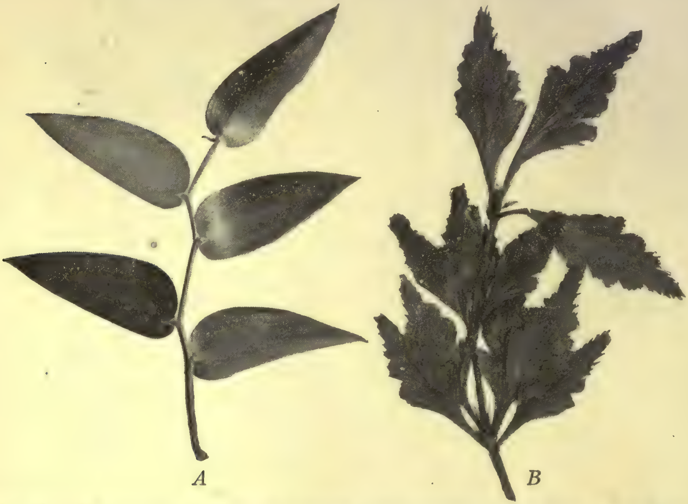

FIG. 58.—Cladophylls: *A*, wedding smilax (the apparent leaves are the modified branches, and the real leaves are the minute scales that subtend them); *B*, *Phyllocladus.*

(2) *Tendrils.*—It was shown (§ 20) that leaves or parts of leaves may develop as tendrils, and this is true also of

branches, as observed in the passion-flower, whose long and very sensitive tendrils appear in the axils of the leaves (Fig. 59). Whether tendrils replace leaves or branches makes no difference as to their structure and activity, but it is of interest to note that different organs may thus be replaced by the same organ.

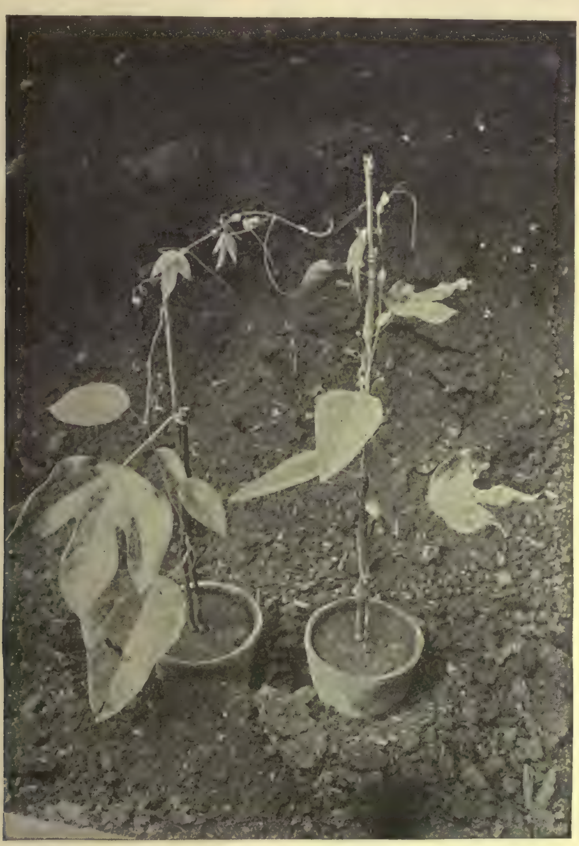

Fig. 59.—Plants of passion-flower showing axillary tendrils.

(3) *Thorns.*—Branches, as well as leaves (§ 20), may develop as thorns; an excellent illustration of a branching thorn being seen in the honey locust (Fig. 60, *A*), and of a simple thorn in hawthorn (Fig. 60, *B*). In dry regions, such as may be found along the Mexican border, thorns and spiny branches are very common; and since in some cases these spiny branches develop into ordinary branches when the plant has a sufficient supply of water, it is thought that such thorns and spines are results of unfavorable conditions for growth. The same statement applies, of course, to those cases in which thorns have replaced leaves.

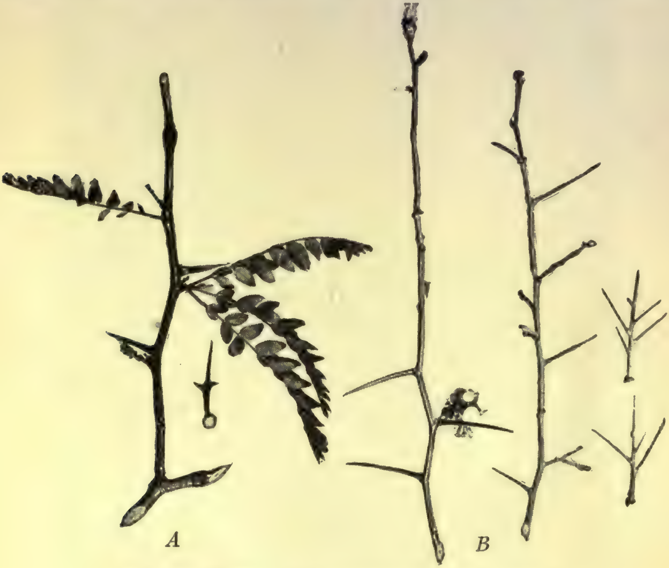

Fig. 60.—Thorns: *A*, honey locust; *B*, hawthorn.

The most common modifications of the stem are those which arise when it is an underground structure. Although it is natural to think of all underground structures as roots, this is far from being true. Since the stem is primarily a leaf-bearing structure, it continues to bear leaves when under ground; but often these leaves are much modified, either reduced in size so as to be mere rudiments, or used for some other purpose. The fact that a subterranean structure bears leaves of some kind indicates that it is a stem and not a root. Since both the stem and its leaves must be considered in connection with the underground habit, the shoot (§ 21) will be considered rather than the stem alone. In general the subterranean shoot is conspicuously a region of food storage. The three following types are the most common.

(4) *Rhizomes.*—This is probably the most common form of subterranean stem. It is usually horizontal, more or less elongated, and much thickened for food storage, and is often called the *rootstock* (Fig. 61). It advances through the soil year after year, often branching, sending out roots beneath and leaf-bearing branches into the air. As it continues to grow at the apex, it gradually dies behind, thus isolating branches in the case of branching rhizomes. It is a very efficient method for the spreading of plants and is extensively used by grasses in covering areas and forming turf. The persistent continuance of some weeds, especially certain grasses and sedges that infest lawns and meadows, is due to this habit (Fig. 62). It is

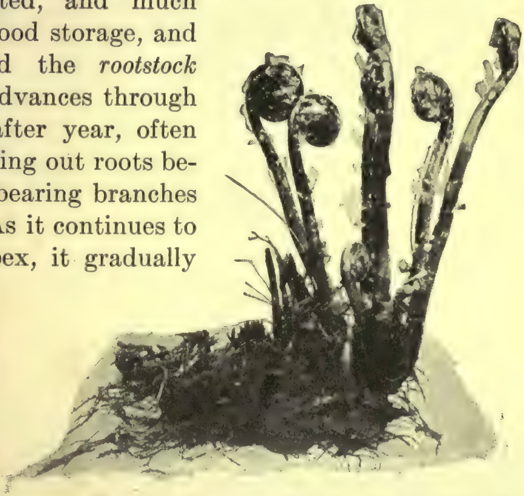

FIG. 61.—Rootstock of a fern (common brake), bearing young leaves.

impossible to remove from the soil all of the indefinitely branching rhizomes, and any nodes that remain are able to send up fresh crops of aerial branches. In many cases only a single aerial branch is sent up each year, as in wild ginger, Solomon's seal (Fig. 63), iris, bloodroot, etc.; in others, leaves and flowers may be sent up separately by the rhizome. In the common ferns, it will be noted, the so-called fronds are simply large leaves developed directly by the rhizome. Perhaps even more familiar is the extensive rhizome system

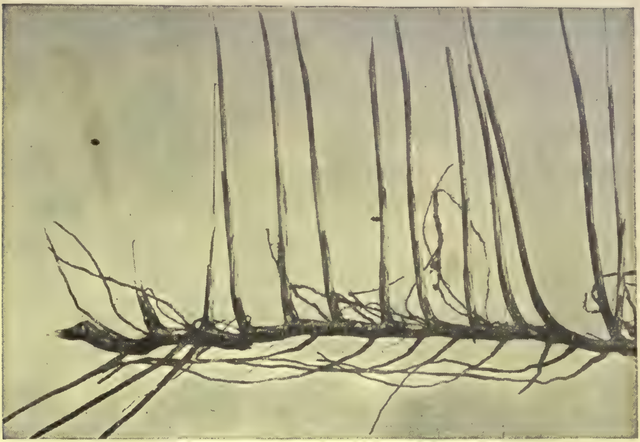

Fig. 62.—Rootstock of a *Juncus*, showing how it advances beneath the ground and sends up a succession of branches; the breaking up of such a rootstock only results in separate individuals.

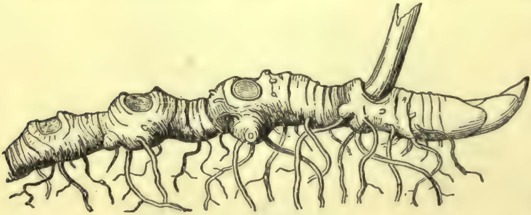

Fig. 63.—Rootstock of Solomon's seal, showing terminal bud, the base of this year's aerial branch, and scars of the branches of three preceding years.—After Gray.

of the water-lilies, from which arise the leaves with large floating blades (pads). Therefore, a rhizome does not necessarily bear only scale leaves, but may develop also leaves that become aerial; and in that case they are usually large. It is evident that in plants possessing rhizomes the subterranean stems are perennial, while the aerial parts may be annual.

(5) *Tubers.*—In some plants the ends of underground stems become very much enlarged for food storage. These enlargements are called *tubers*, the best-known illustration being the common potato (Fig. 64). That it is a stem structure is evident from the fact that it bears very much reduced leaves, in the axils of which are buds, the so-called "eyes." Abnormally developed potatoes often show the shoot character of the tuber very plainly, and in the case of potatoes sprouting it is evident that the eyes have developed into branches. In planting potatoes, advantage is taken of the fact that any node placed in proper conditions may strike root and put out a branch. Since the eyes are branch buds standing at nodes, and any piece of the potato containing a bud is able to produce a new plant, it is customary to cut the potato into pieces, being careful that each piece contains one or more eyes. Heaping up the soil (hilling up) about the base of the potato plant induces the formation of more of the subterranean, tuber-bearing

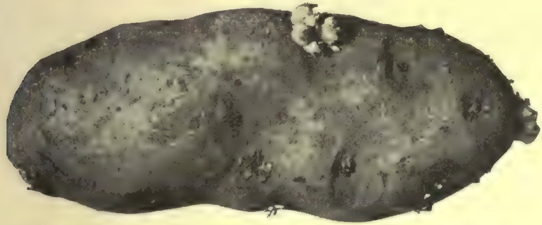
FIG. 64.—Potato tuber showing eyes (scale leaves and axillary buds).

branches. In the tuber called Jerusalem artichoke, which is developed by the subterranean stems of a kind of sunflower, the nodes of the stem and the buds of branches are more conspicuous than in the potato. Fleshy roots, such as those of the sweet potato, should not be confused with tubers.

(6) *Bulbs.*—In some plants the main stem is very short and is covered by numerous thickened, overlapping leaves or leaf bases (usually called scales), the whole structure being a *bulb*. Bulbs such as those of the lily, hyacinth, tulip, and onion are very familiar. In this case the food storage is chiefly in the scales. *Scaly bulbs* are those in which the scales overlap, but are not broad enough to enwrap those within, as the lily bulb (Fig. 65); *coated bulbs* are those in which the broad scales completely enwrap those within, as the bulbs of onions and tulips. Small bulbs, called *bulblets*, are borne by some plants on parts above ground; as, for example, the bulblets that appear in the axils of the leaves of the tiger-lily and those that replace flower-buds in the common onion. These bulblets, when planted, have the power of producing new plants, as do the subterranean bulbs.

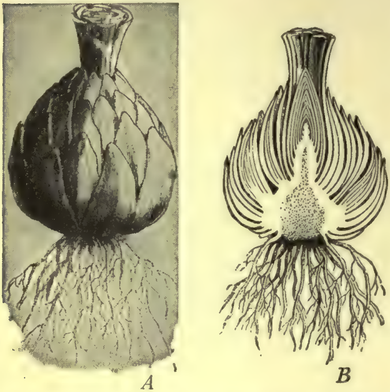

Fig. 65.—Scaly bulb of white lily: *A*, exterior view; *B*, longitudinal section, showing short stem and overlapping scales.—After Baillon

The above subterranean shoots, with their storage of reserve food, enable plants to put out their aerial parts with remarkable promptness and develop them with great rapidity. As an illustration of a situation in which this ability is of great advantage to plants, the *vernal habit* may be mentioned. It is a matter of common observation that the rich display of spring flowers occurs in forests and wooded glens before the trees come into full foliage. The working season of these spring plants is between the beginning of the growing season and the full forest foliage, and the subterranean shoots enable them to send up branches or leaves with great rapidity. After the forest leaves are fully developed, the available light for work beneath the forest crown diminishes, the spring flowers disappear, and the short period of activity does not return until the next season.

It has been observed that many of these underground structures gradually become more and more deeply buried, and it appears that some process of self-burial is going on. For example, it has been observed that if the tuberous underground stem of Jack-in-the-pulpit, often called Indian turnip, be planted in a flower-pot near the surface of the soil, it will be found six inches deeper within a week. This is probably an illustration of exceedingly rapid burial, but enough has been observed of the habits of such plants to indicate that such gradual self-burial of underground parts is very common. Experiments have indicated that this self-burial is not continued indefinitely, but that for each kind of plant there is a normal depth reached by the underground stems. If such stems are planted below their normal depth, the experiments show that there are various methods of ascending to the proper depth.

BUDS

28. **Nature of buds.**—A bud is an undeveloped shoot, whose internodes have not elongated, so that the leaves overlap, forming a more or less compact structure (Fig. 66). It resembles a bulb or bulblet in general structure, except that the overlapping leaves are not thickened as food reservoirs. The outer (older) leaves of the bud protect the

inner (younger) ones, and all the leaves protect the delicate growing apex of the stem or the branch. There are what are called *leaf-buds* and *flower-buds*, but only the former will be considered here.

29. **Position of buds.**—In shrubs and trees the growth of stem and branches is not continuous, but is interrupted during the winter. Preparatory to this interruption a bud is formed at the end of each growing axis, and is called the *terminal bud* (Fig. 66). When it opens the following season it continues the growth of the stem or branch. Buds are formed also in the axils of leaves, usually one bud in an axil, and hence they are called *axillary buds* (Fig. 66). When they develop they form new branches. When the terminal buds are stronger than the axillary buds, the main stem or branches continue to elongate year after year; but if the axillary buds are stronger, the growth of the new branches may replace that of the stem from which they arise. For example, in the common lilac the two buds in the axils of the uppermost opposite leaves develop branches, the terminal bud between them not continuing the growth of the axis, and often not even being formed. Hence the lilac bush is characterized by its forked branching, each axis appearing to end in a pair of branches. Axillary buds do not all develop into branches by any means, but any of them may do so under certain conditions. If the terminal bud is injured or is feeble, the axillary bud or buds nearest to it will be more likely to develop branches; and if the upper axillary buds are injured, the next lower ones will develop, and so on

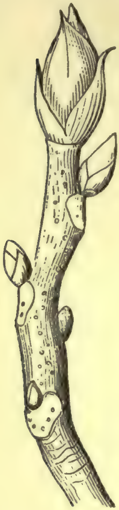
FIG. 66.—Scaly buds of hickory; terminal one strongest; lateral ones axillary as shown by the leaf scars.—After GRAY.

down the axis. Axillary buds may exist for several years without any opportunity to develop, and they may even be overlaid by the growth of the stem on which they stand.

30. **Scaly buds.**—The most conspicuous buds are the so-called *scaly buds*, in which the outermost leaves develop as dry and often hard scales, entirely unlike the true leaves (Fig. 66). These overlapping scales protect the delicate leaves within and the growing apex of the stem from sudden changes of temperature and from moisture, and are often made still more effective against moisture by becoming covered with a sort of varnish or balsam, as in the horse-chestnut and balsam-poplar. The inside of the scales or the young leaves within are often covered with wool, as a further protection against sudden changes of temperature. It is evident that scaly buds are especially adapted to protect delicate structures during the winter and early spring, and hence are characteristic of the shrubs and trees of temperate regions.

In the spring, such buds first swell and then open, the young branch emerging by the lengthening of its internodes, and gradually spreading its leaves. During the opening the scales usually drop off, leaving more or less complete rings of scars about the stem, thus permanently marking the position of the bud. If a branch continues to elongate for a number of years, its age and the amount of growth each year can be determined by the successive sets of bud scars.

31. **Naked buds.**—Buds in which no protective scales are developed, or any other special coverings, are called *naked buds*, and are characteristic of tropical plants, although not entirely lacking in plants of the temperate regions.

32. **Accessory buds.**—In some plants more than one bud may appear in the axil of a leaf, as in the maples, in which three buds occur side by side (Fig. 67). As these buds are most conspicuous in the early spring, the position

of the leaf is indicated by the leaf scar, immediately above which the three buds appear. In the common bush honeysuckle, three to six buds appear in each axil. In all such cases the extra buds are called *accessory buds.*

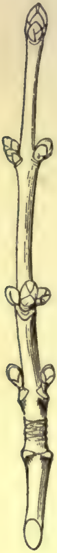

FIG. 67.—Branch of maple, showing terminal, lateral, and accessory buds.—After GRAY.

33. **Adventitious buds.**—Since the tips of stems or branches and the axils of leaves are the usual places for buds, those which occur in other positions are called *adventitious buds.* Such buds appear on stems (on the internodes), roots, and even leaves, and very commonly they arise as a result of injury. On the trunks of trees, even at the base, wounds often result in the formation of buds and the development of vigorous young branches usually called suckers or water sprouts. Often from a stump young shoots arise, and the process of pollarding consists in cutting off the crowns of trees that new branches may be developed in connection with the wound. In the willows, for example, the production of such shoots is so prompt and they are so vigorous and pliable that twigs for basket-work are obtained from them in this way. In propagating plants by root-cuttings, as can be done with blackberries and raspberries, advantage is taken of the fact that some roots can produce buds. In propagating by stem-cuttings it is the axillary buds that develop the new shoots; but in root-cuttings the new shoots arise from adventitious buds. That leaves also may produce adventitious buds is shown in connection with the practise of propagating begonias by leaf-cuttings.

It is evident, therefore, that while plants ordinarily produce terminal and axillary buds, under certain conditions buds may be developed and shoots arise at any place.

CHAPTER IV

ROOTS

34. **General character.**—In general, roots are organized to work in the soil, but this is not true of all of them. The soil roots, however, will be considered first, as being the most common and as exhibiting most clearly the structure

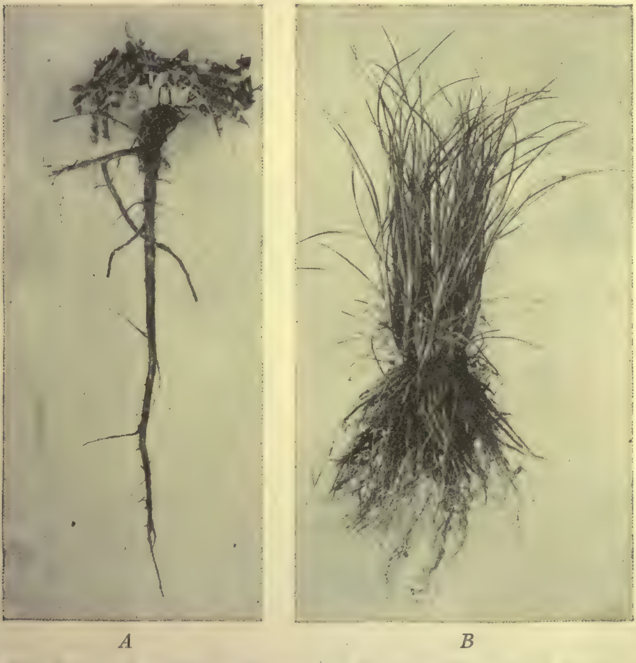

FIG. 68.—Roots: *A*, dandelion with tap-root; *B*, grass with cluster of fibrous roots.

6

and work of roots. One of the most obvious contrasts with the stem in external appearance is that roots bear no leaves or scales, and are not made up of nodes and internodes.

The root that comes from the seed, including all of its subsequent branches, is the *primary root.* In some cases the primary root develops a single prominent vertically descending axis, called the *tap-root,* which gives off small branches, as in the dandelion (Fig. 68, *A*); in other cases the primary root breaks up at once into a cluster of branches, as in many grasses (Fig. 68, *B*). In many cases the tap-root becomes conspicuously thickened for food storage, as illustrated by such common vegetables as radish (Fig. 69, *A*), turnip, and parsnip. In some cases where there is no tap-root, the branches become thickened, forming such clusters of thickened roots as those of the dahlia (Fig. 69, *B*) and of the sweet potato. Roots that arise from the stem or the leaves are *secondary roots.* For example, a subterranean stem or a creeping stem strikes root from the

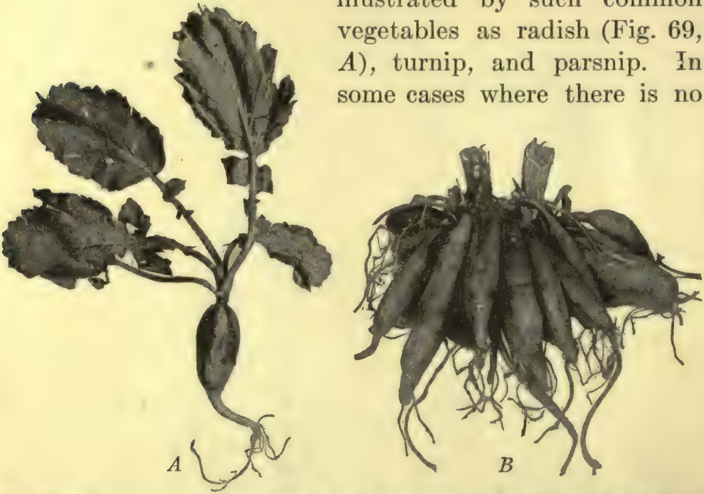

Fig. 69.—Fleshy roots: *A*, radish with fleshy tap-root; *B*, dahlia with cluster of fleshy roots

nodes, and such secondary roots may be the only roots of many plants (Fig. 46). In propagating plants by layering (§ 23) or by cuttings, the roots are necessarily all secondary roots. Even erect stems sometimes send down secondary roots into the soil from the lower joints (Fig. 77), as is very common in corn.

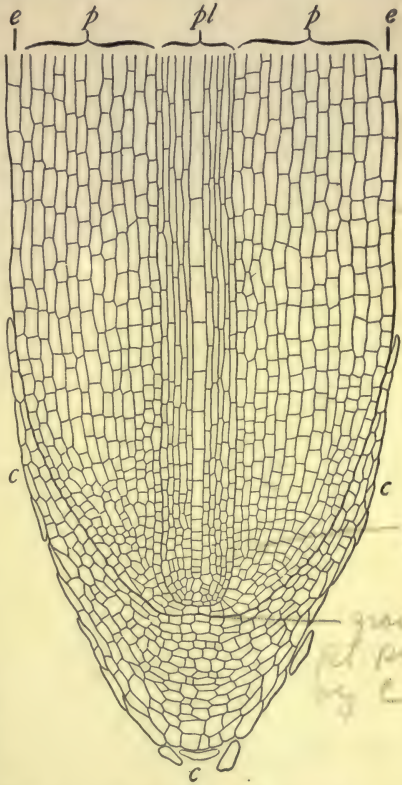

FIG. 70.—Longitudinal section through root-tip of spiderwort, showing central vascular axis (*pl*), cortex (*p*), epidermis (*e*), and root-cap (*c*).

35. **Root-cap.** — The growing tip of each root and rootlet is protected by a cap of cells called the *root-cap* (Fig. 70). This root-cap consists of several layers of cells, the outer ones gradually dying or being worn away as the tip of the root pushes through the soil, and being replaced by new layers which are continually forming beneath. In some plants the root-cap is very easily seen as a conical thickening at the tip of the root; in others it can be demonstrated only by examining under the microscope longitudinal sections through the root-tip. The presence of such a protective cap in the root is in strong contrast with the stem, whose growing tips are protected by overlapping leaves.

36. **Root-hairs.**—A short distance behind the root-cap the surface of the root becomes covered by a more or less dense growth of hairs, known as *root-hairs* (Fig. 71). These hairs are outgrowths, sometimes very long ones, from the superficial cells, a single cell producing a single root-hair. In fact the root-hair is only an extended part of the superficial cell. The root absorbs water and materials dissolved in it from the soil, and the root-hairs enormously increase the absorbing surface. Generally root-hairs do not last very long; but new hairs are being put out by the elongating root as the old ones behind die, so that there is always a zone of active root-hairs near the tip, but none on the older parts of the root.

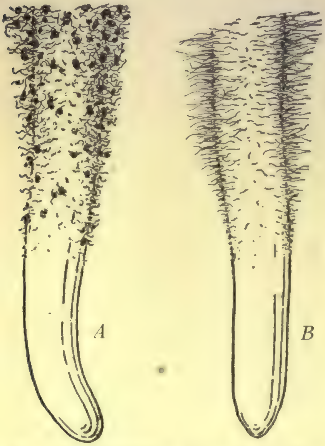

FIG. 71.—Root-tips of corn, showing root-hairs and their position in reference to the growing tip: *A*, grown in soil (higher up the hairs become much more abundant and longer); *B*, grown in moist air.

37. **Internal structure.**—A cross-section of a young root shows two prominent regions (Fig. 73). In the center is a solid vascular cylinder, often called the *central axis*. It will be remembered that in the stems of Dicotyledons and Gymnosperms (§ 24) the vascular cylinder is hollow, enclosing pith. Investing the solid vascular cylinder of the root is the cortex, which often can be stripped from the central axis like a spongy bark. If the section has passed through the zone of root-hairs, they can be seen coming from the superficial cells. A longitudinal section of a root-tip, in which these regions are very young, is shown in Fig. 70.

The wood (xylem) and the bast (phloem) of the vascular cylinder do not hold the same relation to each other as in the stem (§ 24). The vascular cylinder, instead of being made up of vascular bundles with wood toward the center and bast toward the outside, as in stems, is made up of wood and bast strands alternating with each other around the center (Fig. 72). The wood strands radiate from the center like the spokes of a wheel, and the bast strands are between these spokes near their outer ends. This arrangement of wood and bast is peculiar to roots.

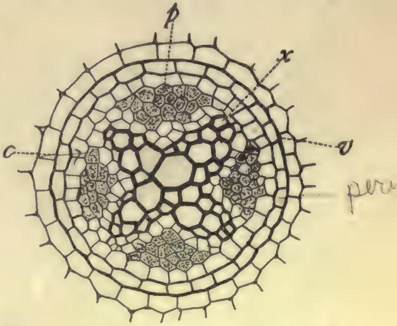

FIG. 72.—Diagrammatic cross-section of a young root, showing the innermost layer of the cortex (*c*) and the vascular cylinder (*v*) containing alternating regions of xylem (*x*) and phloem (*p*).

When roots increase in diameter, a cambium soon begins to form new wood and bast, as in the stems that increase

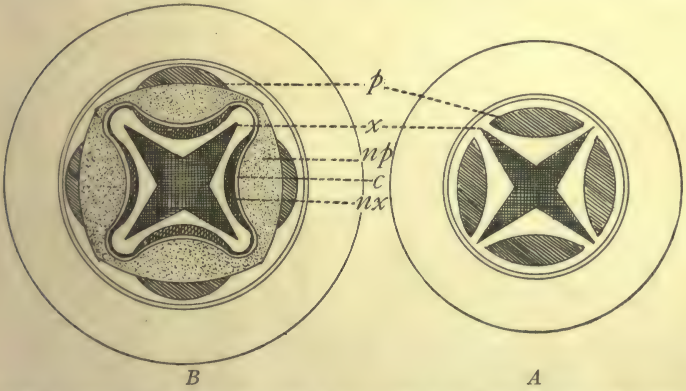

FIG. 73.—Diagram showing the method of thickening the vascular cylinder of a root: *A* represents the cross-section of a young root in which four phloem strands (*p*) alternate with four xylem strands (*x*), the whole bundle region being enveloped by the thick cortex; *B* represents an older root in which there is a continuous zone of cambium (*c*), which is forming on the outside new phloem (*np*) in contact with the old (*p*), and on the inside new xylem (*nx*) alternating with the old (*x*).

in diameter (§ 24). The new wood, however, is not formed in connection with the old wood, but just within the bast, that is, farther in between the "spokes" of old wood, resulting in bundles like those of the stem (Fig. 73). In this way a thickening vascular cylinder is formed, like that of stems that increase in diameter; and presently the cross-section of the root resembles that of the stem. It is evident (Fig. 73) that the principal pith rays separating the vascular bundles of such a root extend inward to the original radiating strands of wood that alternate with the original strands of bast. The vascular bundles of the root connect with those of the stem, and these in turn with those of the leaves, so that throughout the whole plant there is a continuous *vascular system.*

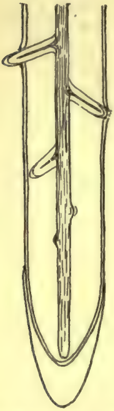

FIG. 74.—Longitudinal section of root of arrow-leaf, showing the branches starting from the central axis and penetrating the cortex.

The origin of the branches of roots is very different from that of stems. In a stem the branch begins at the outer part of the cortex, but in the root it begins at the surface of the vascular cylinder and breaks through the cortex (Fig. 74). If the cortex of a root be stripped off, the branches will be found attached to the central axis, and the perforations made by the branches through the cortex can be seen.

38. **Growth in length.**—The elongating region of the root is much more restricted than that of the stem. It was stated (§ 26) that the elongating region of a stem may extend ten to twenty inches from the tip, or even more; but the elongating region of a root is hardly ever more than two-fifths of an inch, and often not more than half of that. The region of elongation and of greatest elongation should be determined by using such seedlings as those of peas, beans, and corn. When the young roots have become a

half to one inch long, mark as delicately as possible in India ink with a soft camel's-hair brush a series of equally spaced lines, beginning at the tip. Observations at the end of twenty-four to forty-eight hours will discover the region of elongation and of greatest elongation (Fig. 75).

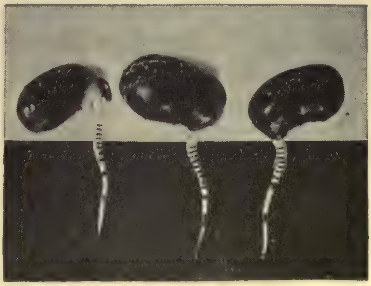

Fig. 75.—Roots of scarlet-runner bean marked with lines one millimeter apart and photographed after forty-eight hours.

39. **The soil.**—Before absorption by roots is considered, it is necessary to know something of the structure of soil. Soil is finely divided rock material, which may be mixed with a greater or less amount of material (called organic material) derived from the broken-down bodies or waste products of plants and animals. However fine the particles of soil may be, they never fit together in close contact, so that there are open spaces everywhere among them. Immediately after a soaking rain these spaces are full of water, but if the soil is one that drains easily, the water gradually disappears from the spaces, and the larger ones are occupied by air. In addition to this occasional water, each particle of soil is invested by a thin film of water, which adheres to it closely, and which never entirely disappears even in the driest soil. The soil water is never absolutely pure, but contains dissolved in it certain materials obtained from the soil.

As types of soil, *sand*, *clay*, and *humus* may be considered. Humus is a soil in which there is intermixed a large amount of decayed plant material; and it is frequently called vegetable mold, or leaf mold, the best illustration being the upper soil of forests. Aside from certain materials that the different soils may supply to the plant, they are especially characterized by their relation to water. The power of a soil to receive and to retain water is a very important consideration in connection with plants. For example, it is evident that the receptive power of sand is high, and its retentive power is low; while in the case of clay the reverse is true. One of the great advantages of humus is that its receptive and retentive powers are better balanced than in sand and clay. It is easy to devise a series of experiments that will show in a rough way the comparative receptive and retentive powers of these three types of soil. It has been shown also that for any given soil, the more finely the particles are divided the better it is for plants. When the soil is turned up with plow or spade, it is dried by the air and pulverized and so put in better condition for plants.

It is evident that in considering the relation of the soil to plants, not only the surface soil must be considered, but also the soil beneath (*subsoil*). For example, if humus rests on sand, the water will drain away much more rapidly than if humus rests on clay. The whole subject of the soil in its relation to plants is one of extreme complexity and is as yet little understood.

40. **Absorption of water.**—To obtain water from the soil, the root not only often branches profusely, but also develops the root-hairs described above (§ 36). Only in the younger portions of the root, that is, in the general region of the root-hairs, is absorption of water effected. The root-hairs push out among the soil particles and come into very close contact with them, the particles sometimes becoming embedded in the wall of the hair (Fig. 76). In this way the films of water adhering to each soil particle are closely applied to the hair, and water passes from them through the wall of the hair into its cavity, and so into the plant. The process by which the water passes in is known

as *osmosis*. As water is absorbed from the films they become thinner, and this loss is supplied from neighboring films. In this way a flow from regions of the soil deeper and more distant than those to which the root reaches is set up toward the films losing water. The water supply may not be able to make good such loss indefinitely; and if so, the films gradually become thinner, until a point is reached when the root-hair can obtain no more water, the film holding tenaciously to its particle of soil. After the roots have obtained all the water they can from the soil, and it seems perfectly dry, it still contains two to twelve per cent of water in the form of films.

The water thus obtained by the root-hairs passes inward through the cortex and enters the wood of the vascular cylinder, and then is free to ascend to the wood of the stem, and so to the leaves.

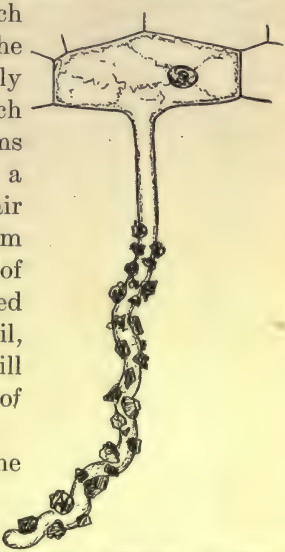

FIG. 76. — Root-hair of wheat, which is shown to be an outgrowth from an epidermal cell, in close contact with soil particles.

It should be understood that the water does not carry into the plant the soil substances dissolved in it; but each dissolved substance, although it must be in solution in order to enter the plant, is turned back or enters upon conditions that belong to itself alone. Certain dissolved substances may not be able to enter at all, and in consequence of this the root has been said to possess a selective power; while other substances may enter with greater or less rapidity at different times, or may even be turned back at certain times. All this diversity of behavior is dependent upon definite laws of physics.

41. Special forms of roots.—Roots in the soil serve the double purpose of anchoring the plant and absorbing water, but certain roots hold other relations and need special mention.

(1) *Prop roots.*—In certain plants roots are sent out from the stem or the branches, and finally reaching the ground establish the usual soil relations. Since these roots resemble braces or props, the name *prop roots* has been applied to them (Fig. 77). A very common illustration is that of the corn-stalk, which sends out such roots from the lower nodes of the stem. More striking illustrations, however, are furnished by the banyan and the mangrove. The banyan sends down from its wide-spreading branches prop roots, which are sometimes very numerous. When they enter the soil they often grow into large trunk-like supports, enabling the branches to extend over an extraordinary area. There is record of a banyan cultivated in Ceylon with 350 large and 3,000 small prop roots, and able to cover a village of one hundred huts. The mangrove is found along tropical and subtropical seacoasts, and gradually advances into the shallow water by dropping prop roots from its branches and entangling the detritus (Fig. 307).

(2) *Water roots.*—If a stem is floating, clusters of whitish thread-like rootlets usually put out from it and dangle in the water. Plants which ordinarily develop soil roots, if brought into proper water relations, may develop water roots. For instance, willows or other stream-bank plants may be so close to the water that some of the root system enters it. In such cases the numerous clustered roots show their water character. Sometimes root systems developing in the soil may enter tile drains, when water roots will develop in such clusters as to choke the drains. The same bunching of water roots may be noticed when a hyacinth bulb is grown in a vessel of water. It is evident

that contact with abundant water modifies the formation of roots, both as to number and character.

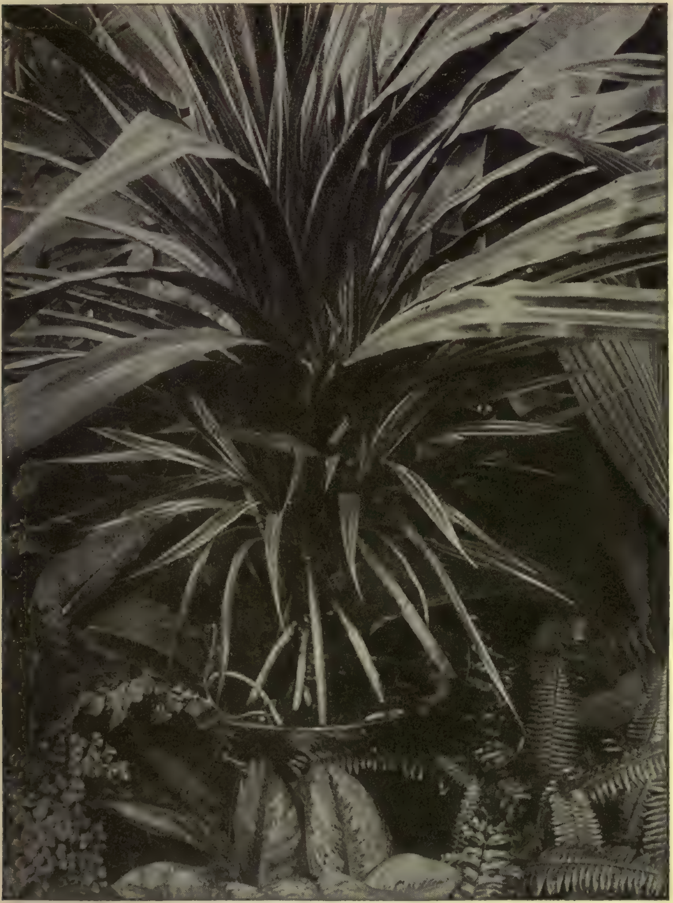

Fig. 77.—A screw pine with prop roots.

(3) *Clinging roots.*—Such roots are developed to fasten the plant body to some support, and may be regarded as

roots serving as tendrils. In the trumpet-creeper and poison-ivy these tendril-like roots cling to various supports, such as stone walls and tree trunks, by sending minute branches into the crevices. In such cases, however, the plant has also true soil roots.

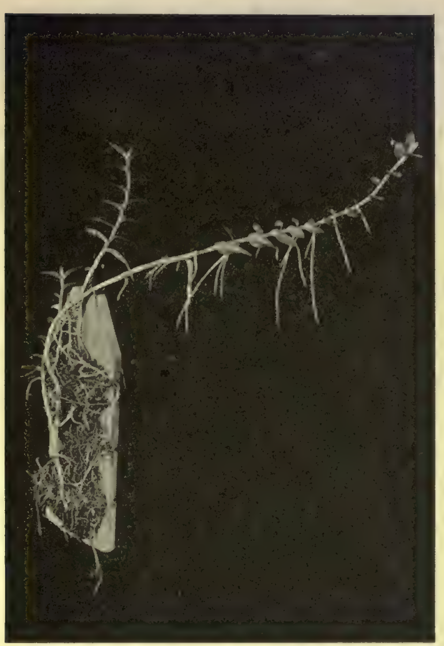

Fig. 78.—An orchid with aerial roots.

(4) *Air roots.*—Some plants have no soil connection at all. In the rainy tropics, where it is possible to obtain sufficient moisture from the air, there are many such plants, notable among which are the orchids, to be observed in almost any greenhouse. Clinging to the trunks of trees, usually imitated in the greenhouse by nests of sticks, they send out long roots which dangle in the moist air (Fig. 78). Such plants are called *epiphytes*, the name indicating that they perch upon other plants and have no connection with the soil (Fig. 79). A very common epiphyte of our Southern States is the common long moss or black moss (although it is by no means a moss) that hangs in stringy masses from the branches of live-oaks and other trees (Fig. 80).

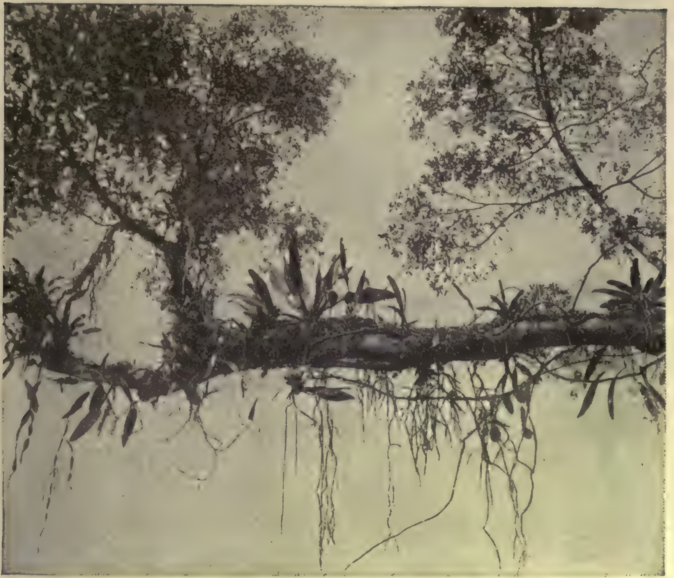

FIG. 79.—A group of aerial plants (epiphytes) in a tropical forest. —After KARSTEN and SCHENCK.

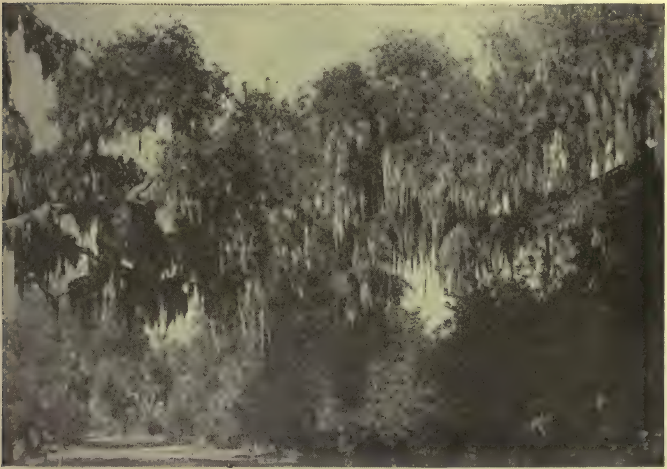

FIG. 80.—Live-oaks covered with long "moss."

CHAPTER V

GERMINATION OF SEEDS

42. **Introductory.**—In the preceding chapters the structure and the work of the three great nutritive organs (leaf, stem, and root) of the higher plants were considered. In studying the germination of seeds, these organs may be observed assuming their various positions and relations, and the student may be introduced to certain important facts.

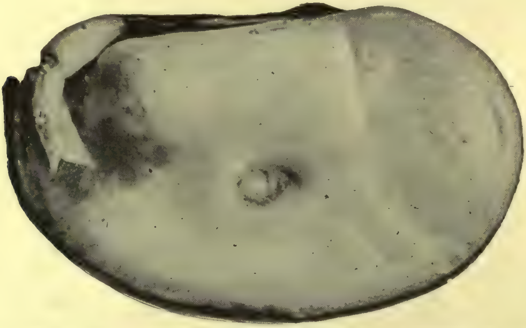

FIG. 81.—Section of bean; removing one cotyledon, and showing the testa, the remaining cotyledon, the hypocotyl (its tip in position to emerge), and the plumule.

Perhaps the most common seed used in class study of seed germination is the garden bean, although other seeds should be germinated in the laboratory, and, when possible, studies of germination should be extended beyond the laboratory.

43. **General structure of the seed.**—It is very common to study even the surface of the seed in great detail, but

only such features as have an evident bearing upon its germination will be considered here. The seed is invested by a hard coat (*testa*), which in some seeds is extremely hard, and is evidently a protective structure during the more or less prolonged period of rest. Within the testa the young plantlet is packed, at this stage called the *embryo* (Fig. 81). The process of germination is the escape of this plantlet from the testa. If the embryo of the bean be removed from the testa—better done after soaking in water for some time—and straightened out, it will be found to consist of three distinct parts (Fig. 82). The most conspicuous of these is the two "halves" of the bean, which are the seed-leaves (*cotyledons*) gorged with reserve food. These cotyledons stand upon a minute stem, which in the seed is curved up against them, and which is called the *hypocotyl*, a name applied to the peculiar stem of an embryo. Between the cotyledons, and arising from the top

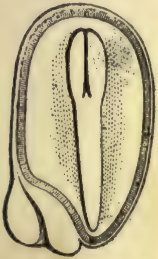

Fig. 81*a*.—Section of violet seed, showing embryo, endosperm, and testa.

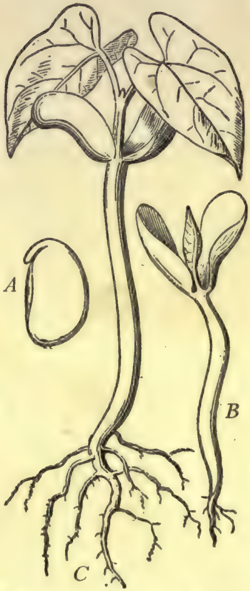

Fig. 82.—Seedling of bean: *A*, embryo removed from testa; *B*, young seedling showing hypocotyl, cotyledons, and plumule; *C*, older seedling showing the first internode and leaves of the stem.—After Gray.

of the hypocotyl is a bud, called the *plumule*, from which the future leafy stem is to develop. In many seeds the reserve food is not stored in the cotyledons, but in a special tissue surrounding the embryo, which in general may be called *endosperm*. In the violet seed, for example, within the testa is the endosperm, and embedded in the endosperm lies the embryo (Fig. 81*a*).

44. **Conditions for germination.**—The length of time seeds may retain their vitality varies with different plants. In nature they are expected to germinate in the growing season following their maturity; but many are known to retain the power of germination for several years if kept in proper conditions, chief among which, apparently, is dryness. The stories of the germination of wheat and corn obtained from the wrappings of mummies have proved to be myths.

The conditions required for germination are abundant moisture, suitable temperature, and a supply of oxygen (which means access of air). Seeds vary greatly in the amount of heat necessary for germination, as may be inferred from the fact that some seeds germinate in early spring or even on the melting snow-fields of alpine and arctic regions, while others need the heat of the tropics.

45. **Absorption of water.**—When a seed has been placed in the proper conditions for germination, the first visible result is its swelling through the absorption of water. The amount and force of this swelling may be observed by placing a quantity of seeds in a tumbler of water and putting various weights on the mass. It is entirely clear also that oxygen has been passing in, for the seed gives off carbon dioxide and heat. That heat is given off by a germinating seed is made very plain in the process of malting, in which a large mass of barley is put in germinating conditions in a confined space, and the combined heat from all the seeds becomes very evident.

46. **Respiration.**—The escape of carbon dioxide, which follows the taking in of oxygen, is the superficial indication that the very important process called *respiration* is going on—a process that is essential not only to every living animal and plant, but also to every living cell. Just what happens in respiration is very uncertain; but it involves a series of changes in the living substance (*protoplasm*) itself—changes which are made possible by the presence of oxygen, and among whose results are the liberation of carbon dioxide as a waste product, and of energy for plant work, such as growth and movement. A plant, therefore, cannot work without respiration; and if it cannot work it ceases to live.

The contrast between photosynthesis (§ 14) and respiration should be kept distinctly in mind, as the former process so masks the latter in green plants exposed to light that the occurrence and the importance of respiration in them is not always fully appreciated. It was once customary to contrast plants and animals by stating that the former take in carbon dioxide and give out oxygen (photosynthesis), and the latter take in oxygen and give out carbon dioxide (respiration). It is evident that all living things, whether plants or animals, are dependent upon respiration; while green plants when exposed to light can also do the work of photosynthesis. The contrast between the two processes may be made still more evident by the following statement: photosynthesis occurs only in green cells, requires light, uses carbon dioxide, liberates oxygen, makes organic material, and accumulates energy; while respiration occurs in every living cell, does not require light, uses oxygen, liberates carbon dioxide, uses organic material, and liberates energy.

47. **Digestion.**—Before any growth of the embryo can take place the reserve food must be changed. Most frequently in seeds the storage form is starch, but starch is insoluble and therefore cannot move out of the cells in

which it is stored. Accordingly it must be changed into a soluble form; and this work is commonly done by a substance called an *enzyme,* which is produced by the living substance (protoplasm) of the cell. There are numerous enzymes, which act upon different substances; but the one most frequently found in seeds is that called *diastase,* which has the power of converting starch into one of the soluble sugars. This process of converting insoluble food into a soluble form is *digestion,* and in ordinary seeds the starch is digested and becomes sugar. All of this work preparatory to growth accounts for the activity noted in the two preceding sections. The food being in the form of a soluble sugar can leave the storage cells and pass to the regions where growth occurs.

48. **Assimilation.**—In a germinating seed the soluble sugar produced by digestion passes in solution from cell to cell, according to the laws of osmosis, until it reaches cells where growth is taking place; that is, where the protoplasm is forming new cells by dividing those already formed, and enlarging the new ones until each one is as large as the cell of which it was a division. This cell division and cell growth are going on very actively in the hypocotyl and plumule of the germinating seed; and when the sugar in solution reaches the active cells, it is used in building up the active protoplasm, which is being broken down by its activity. This transformation of food into protoplasm, by numerous intermediate steps, is *assimilation.*

49. **Proteids.**—Thus far we have considered only carbohydrate foods, but in building up protoplasm the carbohydrates are first used in the manufacture of *proteids.* Just how proteids are formed is very uncertain, but they are more complex than carbohydrates; and in addition to the carbon, hydrogen, and oxygen of the carbohydrates, proteids contain other elements, notable among which are nitrogen, sulphur, and phosphorus, and these enter the

plant in various compounds found in the soil. The white of an egg is an illustration of a proteid; and meat in general is a proteid food, as contrasted with bread, which is a carbohydrate food. In many seeds proteid food is stored in the form of *aleurone grains*. For example, a section of a wheat grain, or the grain of any common cereal, shows aleurone grains in the outer layer of endosperm cells, just inside of the testa; while the other endosperm cells contain starch grains.

50. **Fats.**—In addition to carbohydrates and proteids, some plants form fats, the third kind of organic food; and these fats are sometimes stored in the seeds in liquid form (in small drops), as in the castor-bean, flaxseed, etc. Fats contain carbon, hydrogen, and oxygen as do the carbohydrates; but while in the carbohydrates the hydrogen and oxygen occur in the proportion of two to one (H_2O), in the fats the proportion of oxygen is much less. In addition to the oil obtained from the seeds mentioned above, olive oil and cotton-seed oil may be mentioned as plant fats of commercial importance.

51. **Escape of the hypocotyl.**—The first part of the seedling to push out of the testa is the tip of the hypocotyl, which is to develop the root. It is soon evident that this elongating tip directs its growth downward, that is, toward the earth, even if it has to curve about the seed to do so (Fig. 83). It is exceedingly sensitive to surrounding influ-

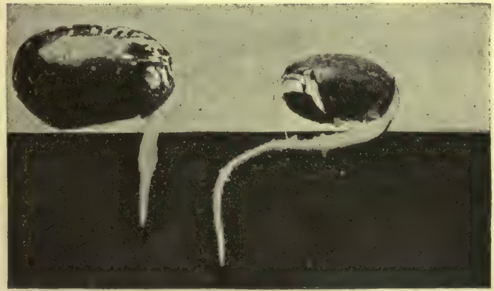

FIG. 83.—Germinating beans: the bean to the left has not been moved; the one to the right was turned 90° after it had reached the stage of the other

ences, a condition that is called *irritability.* The outside influences that affect irritable organs are called *stimuli;* for example, among animals light is a stimulus to the eye.

52. **Geotropism.**—The young root, developing at the end of the hypocotyl, is very sensitive to gravity, a condition that is called *geotropism,* the root being said to be *geotropic.* The word means "directed by the influence of the earth," what is commonly called gravity acting as a stimulus. If the root-tip, when it pushes out of the testa, is directed upward or horizontally, gravity acts as a stimulus and the irritable root responds by developing a curvature that directs it downward (Fig. 83). This is only one way of responding to the stimulus of gravity; and since this way directs the organ toward the source of the stimulus, the organ is said to be *positively geotropic.* If the same stimulus and response that directs the root-tip toward the soil continues to direct it within the soil, it continues to grow directly downward and becomes a tap-root (Figs. 68 and 89). When such a root, having entered the soil, begins to send out branches, these do not respond to the stimulus of gravity as does the tap-root, for they extend through the soil in every direction, and are evidently not positively geotropic.

53. **Hydrotropism.**—The root is very sensitive also to the presence of moisture, a condition that is called *hydrotropism,* the root being said to be *hydrotropic.* The word means "directed by the influence of moisture," the moisture acting as a stimulus, and the root being *positively hydrotropic.* Since ordinarily the stimuli of moisture and gravity act from the same general direction upon the root, the responses are not contradictory. It is of interest, therefore, to arrange an experiment that will make them contradictory. An erect support, shaped as shown in Fig. 84, is covered with bibulous paper which is kept moist.

To the inward sloping surface is pinned a seedling whose root has well started. The photograph (Fig. 84) shows that the root, continuing to grow, has turned from the vertical direction under the stimulus of the moisture in the bibulous paper, and is pursuing a general direction that is a resultant between the two stimuli. A more detailed observation of such an experiment shows that the root-tip sometimes turns toward and sometimes away from the moist paper.

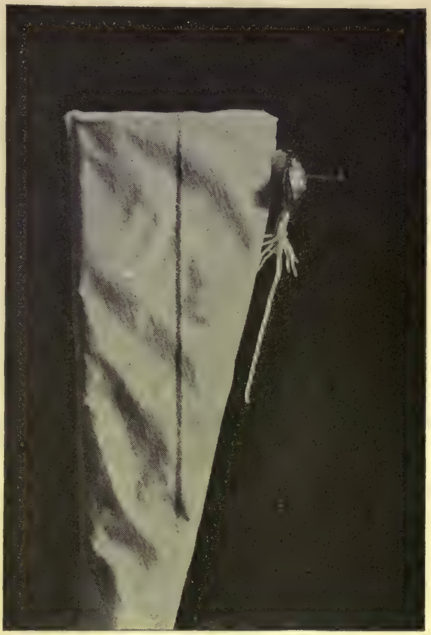

Fig. 84.—A bean seedling showing the response of the root when the stimulus of gravity is from one direction and that of moisture from another.

54. **Escape of the cotyledons and the plumule.**—After the root with its branches has anchored the plantlet to the soil, the hypocotyl begins to elongate rapidly; and since the cotyledons are still within the testa this elongation results in the development of an arch, the *hypocotyl arch* (Fig. 85). As the arch constantly seeks to straighten itself, the upward pull on the cotyledons finally draws them out of the testa and the hypocotyl straightens. The cotyledons, however, have done their work, and although they may become green and persist for some time, in the bean they are of no further importance. It is the escape of the

plumule that is especially significant, for it develops the shoot (Fig. 85).

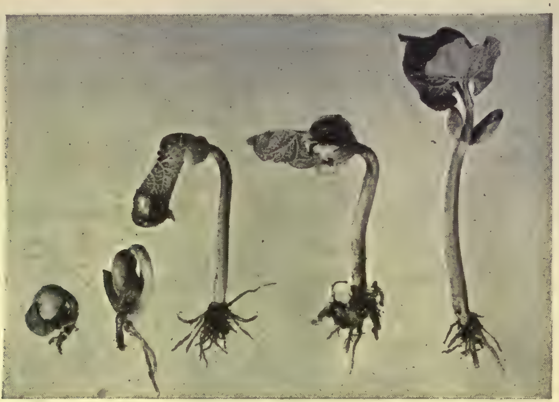

FIG. 85.—A series in the germination of the garden bean, showing the hypocotyl arch, the pulling out of the cotyledons and the plumule, and the straightening of the hypocotyl.

With the establishment of roots in the soil and the exposure of green leaves to the light and air, germination is over; for the plant is able to make its own food.

55. **Phototropism.**—The stem is sensitive to the direction of rays of light, a condition that is called *phototropism*, the stem being said to be *phototropic*. The word means "directed by the influence of light," the same stem

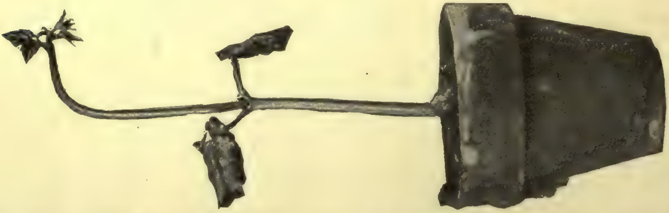

FIG. 86.—A bean seedling that was placed in a horizontal position and after two hours photographed.

appearing in the word "photograph." The term *heliotropism* is often used, meaning "directed by the influence of the sun"; but while the sun is the usual source of light, it is not the only one. It should be noted that it is not light in general that acts as the stimulus, but the *direction* of the rays of light. The response of the stem to this stimulus is to turn directly toward the source of the light rays; that is, the stem is *positively phototropic*. Fig. 86 shows a bean seedling that was placed in a horizontal position and two hours afterward photographed. Fig. 87 shows the same plant completely inverted, allowed to grow for two days, and then photographed. In both cases the strong curvature developed in response to the stimulus of light is very evident, the tip of the stem in both experiments being directed toward the source of light.

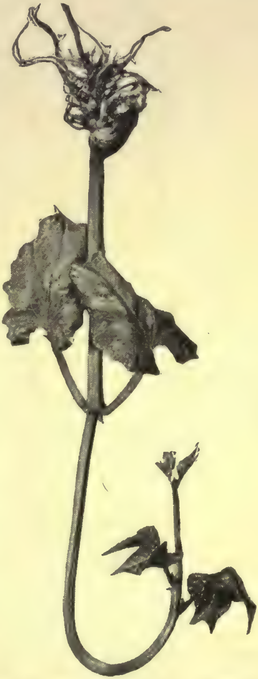

FIG. 87.—The same seedling shown in Fig. 86, completely inverted, and after two days photographed.

It should be remembered that these stimuli that influence direction call forth a response only when the organ is out of line, and the response or *reaction* is a curve that brings it back into line. It is also important to note that the sensitive or irritable region of an organ is not necessarily the region in which the reaction occurs; and this means that the stimulus has been transmitted in some way from the irritable cells to those that respond, for example, by developing a curvature. Nor does the reaction follow the stimulation immediately; for there is an interval, known as *reaction time,* which is generally much longer in plants than in animals. The reaction time may be several hours, but the movement of the leaves of the sensitive-plant (§ 17) and the snapping shut of the leaves of *Dionæa* (§ 20) follow the stimulation with remarkable promptness.

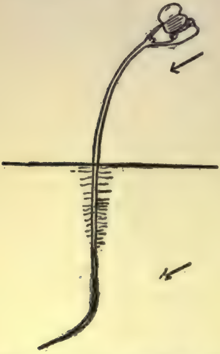

FIG. 88.—A seedling of white mustard grown in water and exposed to weak light, showing the positive phototropism of the stem and the negative phototropism of the root; the arrows indicate the direction of the rays of light.

The main stem in most cases is *positively phototropic,* as shown before (Figs. 86 and 87); but it is also *negatively geotropic.* The branches, however, may respond to these stimuli in a very different way, usually extending in a more or less horizontal direction, and being mainly *transversely geotropic.* The leaves, also, are usually neither positively nor negatively phototropic, but are directed horizontally, being *trans-*

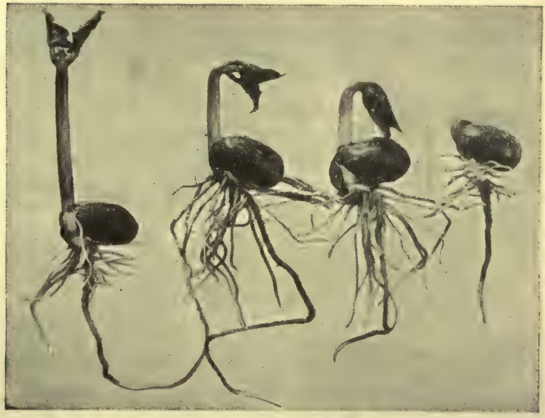

FIG. 89.—A series in the germination of the scarlet runner bean.

versely phototropic. The adjustment of the leaf-blades to the new direction of the light may be seen in Fig. 87.

The root also is phototropic, turning directly away from the source of light; that is, it is *negatively phototropic.* Fig. 88 shows a seedling of white mustard so arranged that both stem and root are exposed only to weak light, the former showing positive, the latter negative phototropism. It is interesting to note that a tap-root being positively geotropic, positively hydrotropic, and negatively phototropic, all of its responses under ordinary conditions combine to direct it into the soil.

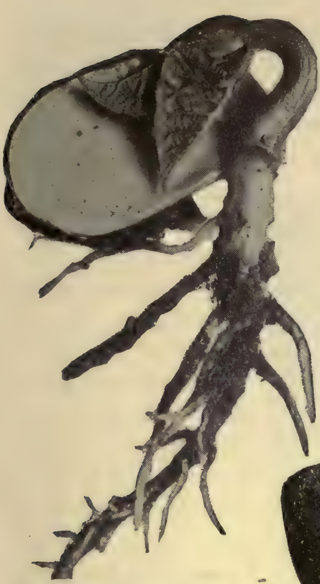

FIG. 89*a*.—First stage of the series shown in Fig. 89; one cotyledon removed to show the relation of parts, and the arch developed by the first internode.

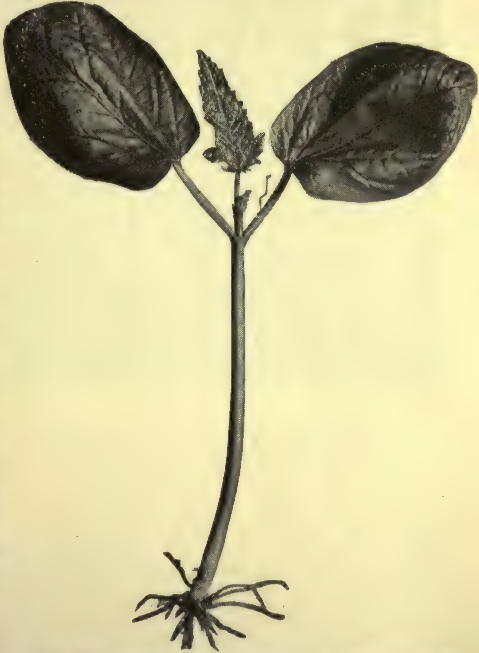

FIG. 90.—Seedling of castor-bean, showing large and green cotyledons.

56. Other seeds.—It must not be supposed that all of the details of germination given for the garden bean are found in the germination of all seeds. The conditions for germination, and such life processes as respiration, digestion, etc., belong to the germination of all seeds; but the relations of parts to one another and the details of the escape of the young plantlet vary widely, and should be examined in as many plants as possible. For example, in the scarlet-runner bean the cotyledons are not usually freed from the testa, the first internode of the stem developing the arch and freeing the leaves, as may be seen in the series shown in Figs. 89 and 89*a* which is completed by Fig. 57.

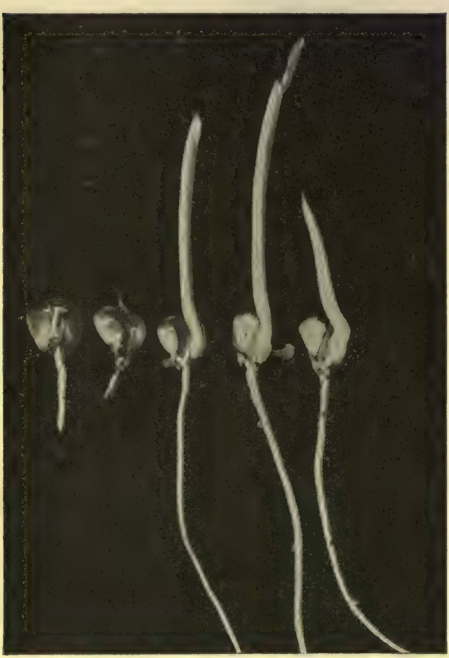

Fig. 91.—Seedling of corn at several stages, showing the superficial position of the embryo, the unfolding leaves, and the roots; the single cotyledon is not seen, remaining in close contact with the endosperm.

Seeds such as peas, castor-bean, squash, and corn also should be germinated, as they show important variations. For example, in the pea and the acorn the cotyledons, so gorged with food as to have lost all power of acting as leaves, are never extricated from the testa; but the plumule is pushed out by the elongation of the cotyledons at their bases into short or sometimes long stalks. In the castor-bean and the squash, the cotyledons not only escape from the testa, but become green and work like ordinary leaves (Fig. 90).

In corn, as in all the cereals, the embryo lies close against one side of the seed so that it is completely exposed by the splitting of the thin skin that covers it. In this case the single cotyledon is never freely expanded, but remains as an absorbing organ in contact with the starch-containing endosperm, while the root grows in one direction, and the stem, with its succession of unsheathing leaves, grows in the other direction (Fig. 91).

CHAPTER VI

ALGÆ

57. General characters.—Algæ are the simplest green plants, and it is thought that the higher plants have been derived from them. They grow in the water, and hence their habits are adapted to a water environment. They are often called seaweeds, but although they are very abundant along seacoasts they are also abundant in fresh waters. Some of them are so small that the individual bodies are visible only under the microscope, and there is every gradation in size from this to the bulky bodies of certain marine forms.

Although all Algæ contain chlorophyll, and hence are able to make their own food (§ 14), they do not all appear green; for in many of them the chlorophyll is obscured by other coloring matters. The four great groups of Algæ are named from the general color of their bodies, although it must be remembered that they all contain chlorophyll, which makes them independent. Some representatives of each group are selected for description, but they or others like them must be examined before any real knowledge of them can be obtained.

1. BLUE-GREEN ALGÆ (*Cyanophyceæ*)

58. Glœocapsa.—These plants form blue-green or olive-green patches on damp tree trunks, rocks, walls, etc. By means of the microscope these patches are seen to be composed of multitudes of spherical cells, each cell representing a complete *Glœocapsa* body. One of the peculiarities of the plant is that the outer part of the cell wall becomes mucilaginous, swells, and forms a jelly-like sheath. Among the cells examined there will be found some that are dividing, a wall extending across the spherical cell and dividing it into hemispheres. Each hemisphere is a new plant which grows as large as the parent cell and then divides in turn. The mucilaginous walls hold the cells together, and so they are found in groups of various sizes (Fig. 92). This method of reproduction by cell-division is the simplest kind of reproduction.

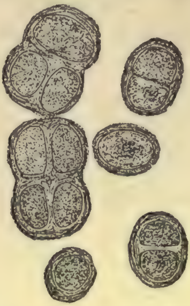

FIG. 92.—*Glœocapsa:* showing single cells, and small groups that have been formed by division and are held together by the enveloping mucilage.

59. Nostoc.—These plants occur in jelly-like masses in damp places. If the jelly be examined, it will be found to contain embedded in it numerous

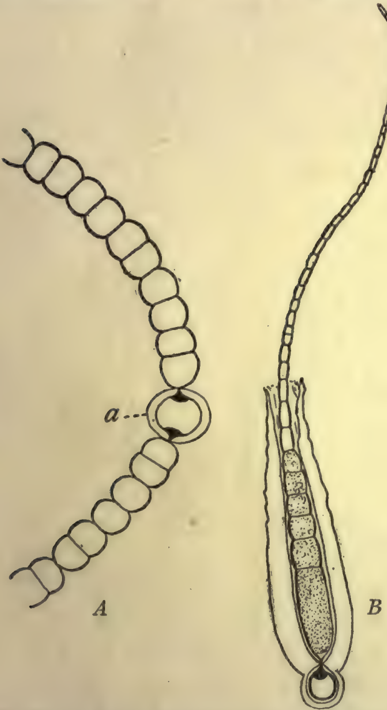

FIG. 93.—*A*, *Nostoc:* showing the chain-like filament and a heterocyst (*a*); *B*, *Glœotrichia:* showing mucilage sheath, basal heterocyst, and tapering apex.

cells like those of *Glœocapsa,* but they are strung together so as to form chains of varying lengths (Fig. 93, *A*). The jelly in which these chains are embedded is formed from the cell walls, as in *Glœocapsa,* but it is much more abundant. One notable fact in *Nostoc* is that the cells of a chain are not all alike, for at irregular intervals there occur larger colorless cells, called *heterocysts* (Fig. 93, *A*, *a*), a name which means simply "other cells." It is observed that when the chain breaks up into fragments, each fragment is composed of the cells between two heterocysts. The fragments wriggle out of the jelly matrix and start new colonies or chains, each cell dividing to increase the length of the chain. A common plant related to *Nostoc* shows still more differentiation in the cells of the filament, the heterocyst being at the base, and the end cells forming a tapering and sometimes whip-like termination (Fig. 93, *B*).

That each cell of *Nostoc* is an individual is evident from the fact that a single cell separated from the chain continues to live and divides; and therefore the chain is a colony of individuals, each one reproducing by cell-division.

60. **Oscillatoria.**—These plants are found as bluish-green slippery masses on wet rocks, or on damp soil, or freely floating. They are simple filaments composed of very short flattened cells (Fig. 94), and the name refers to the fact that the filaments exhibit a peculiar oscillating movement. A filament is really a row of independent cells packed in a mucilaginous sheath, like coins in a coin-case. The cells are evidently flattened by mutual pressure, for the free face of the terminal cell is rounded (Fig. 94, *B*); and if a filament is broken, and a new cell surface exposed, it at once bulges out. If a single cell of the filament is free from all the rest, both flattened faces become rounded, and the cell becomes spherical. It is evident that pressure within the cell distends the elastic wall whenever it is free. Each cell is able to divide, forming new cells and thus

lengthening the filament, which may break up into fragments, each fragment forming a new filament.

Although *Oscillatoria* is regarded as a filamentous colony of individuals, the peculiar waving and gliding movements of the filament show the cells working together. The transition from a colony of one-celled independent individuals to an individual of many interdependent cells is insensible and indefinite.

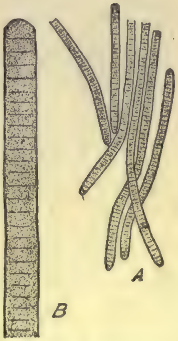

FIG. 94.—*Oscillatoria:* *A*, group of filaments; *B*, a single filament more enlarged.

61. **Conclusions.**—These three forms of blue-green Algæ will serve to illustrate the general features of the whole group. The name of the group refers to the fact that in addition to the chlorophyll the cells contain a characteristic blue coloring matter which does not mask the green, but combined with it gives a bluish-green tint to the plants when seen in masses. Not all the blue-green Algæ are bluish-green in tint, however; for the presence of other substances may disguise it, and the color may be yellow, or brown, or even reddish. For example, the largest of all the blue-green Algæ has given name to the Red Sea.

The group is sometimes called the green slimes on account of the characteristic slimy, mucilaginous walls. They are very simple, being one-celled plants, the cells occurring singly or in chains and filaments. The reproduction is exclusively by means of cell-division; and since the cells that divide are ordinary working cells, this method of reproduction is usually called *vegetative multiplication.* In plants whose bodies are many-celled, cell-division usually results in the growth of the individual rather than in the formation of new individuals. The power of motion is marked in certain forms, and there is also a tendency shown by the cells of a colony to work together. Different forms of cells are exhibited by *Nostoc;* and this condition, spoken of as the *differentiation* of cells, implies also a differentiation of work.

62. **Presence in water reservoirs.**—Until recently the Algæ were thought to be of no importance to man; but it is now known that the offensive odor and taste too often observed in drinking water are due almost entirely to them, and chief among the polluting forms are the blue-green Algæ. This pollution of water becomes very conspicuous when it occurs in city reservoirs or in ponds, and various methods of purification have been suggested. Of these none had proved satisfactory, until in 1904 the Department of Agriculture at Washington announced that an effective method of destroying the Algæ or preventing their appearance had been discovered. It consists in introducing into the water a solution of copper sulphate so dilute that it is tasteless and harmless to man; but the warning is given that each reservoir or pond must be studied before the proper amount of the solution can be known.

2. GREEN ALGÆ (*Chlorophyceæ*)

63. **Pleurococcus.**—These plants are exceedingly common, occurring in masses, especially on the north side of tree trunks, old fences, etc., and looking like a green stain. After a few damp days the green of the masses becomes more vivid and noticeable. These finely granular green masses are found to consist of multitudes of spherical cells, resembling those of *Glœocapsa,* except that there is no blue with the chlorophyll, and the cells are not embedded in a jelly-like substance derived from the walls.

The cells may be solitary, or they may cling together in groups of various sizes (Fig. 95). Cells that have just divided may be observed easily, the evidence being that the two daughter cells have not yet rounded off or separated, so that they appear as two halves of the parent cell. Even before they separate they may divide again, and thus a group of cells may be formed. *Pleurococcus,* therefore, is another illustration of an extremely simple plant, in that it consists of one cell and reproduces by cell-division.

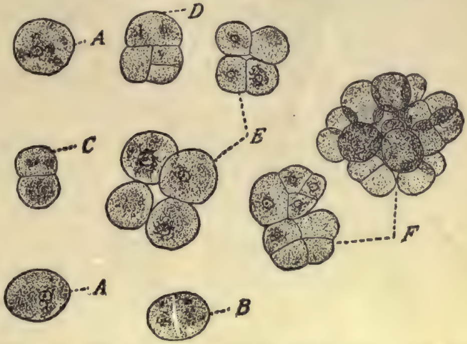

FIG. 95.—*Pleurococcus: A*, the adult plant, with its nucleus; *B-E*, various stages of division in producing new cells; *F*, colonies of cells that have remained in contact.

It would be hard to imagine a simpler plant, and the plant kingdom can be thought of as beginning with individuals consisting of one green cell and reproducing by division. This one cell, however, absorbs material, makes food, assimilates it, conducts respiration, etc.; in fact, does all the work of living carried on by plants with roots, stems, and leaves, although they may contain millions of cells.

64. **The plant cell.**—*Pleurococcus* may be used to illustrate the conspicuous features of a living plant cell. Bounding the cell there is a thin, elastic *cell-wall,* composed of a substance called *cellulose.* The cell-wall, therefore, constitutes a delicate sac, which contains the living substance known as *protoplasm.* It is the protoplasm that has formed the wall about itself, in the same sense that a snail deposits the shell about its body. The protoplasm is organized into various structures which are called *organs of the cell.* One of the most conspicuous protoplasmic organs is the *nucleus,* a comparatively compact and usually spherical body, and generally centrally placed within the cell (Fig. 95, *A*).

In the great majority of cells there is a single nucleus, and all about it, filling the general cavity within the cell-wall, is a mass of much less dense protoplasm, known as *cytoplasm.* The cytoplasm seems to form the general background or matrix of the cell, and the nucleus lies embedded within it. Another protoplasmic organ of the cell is the *plastid.* Plastids are relatively compact bodies, and variable in form and number. The most common kind of plastid is the one that contains chlorophyll, and hence is known as the *chloroplastid* or *chloroplast.* An ordinary cell of an alga, therefore, consists of a cell-wall, within which the protoplasm is organized into cytoplasm, nucleus, and chloroplasts. With proper staining the nucleus and the chloroplasts of *Pleurococcus* can be seen; but these structures may be seen more distinctly and with much less trouble in the cells of a moss leaf (Fig. 96).

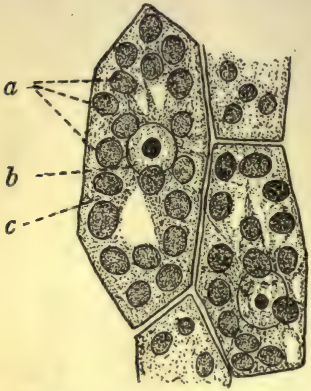

FIG. 96.—Cells of a moss leaf, showing chloroplasts (*a*), nucleus (*b*), and cytoplasm (*c*).

The cell-wall is elastic, so that the cell can be compressed or inflated. The single cell of *Pleurococcus,* unless pressed upon by neighboring cells, retains a spherical form as long as it is alive, a fact which shows that there is constant and uniform pressure on the wall from within the cell. It is found that this pressure is due to the absorption of water in sufficient amount to stretch the wall, this distended condition of the cell being called *turgor,* a name indicating that the cell is turgid. *Pleurococcus* retains its spherical form, therefore, because it is turgid; and the bulging of free walls of *Oscillatoria* (§ 60) is due to the turgor of the cells.

65. Ulothrix.—These are bright green, thread-like plants found in the shallow, moving water of streams or lake margins, where they are anchored to sticks or stones. Each plant is a simple (unbranched) filament, composed of a single row of cells; and the cells are all alike excepting that the lowest one is usually colorless, and is elongated and more or less modified to act as a holdfast, anchoring the filament to its support (Fig. 97, *A*). With the possible exception of the holdfast cell, in each cell there may be seen a nucleus and a single chloroplast of peculiar form, being a thick cylinder investing the rest of the cell-contents. As seen under the microscope in optical section, the cylin-

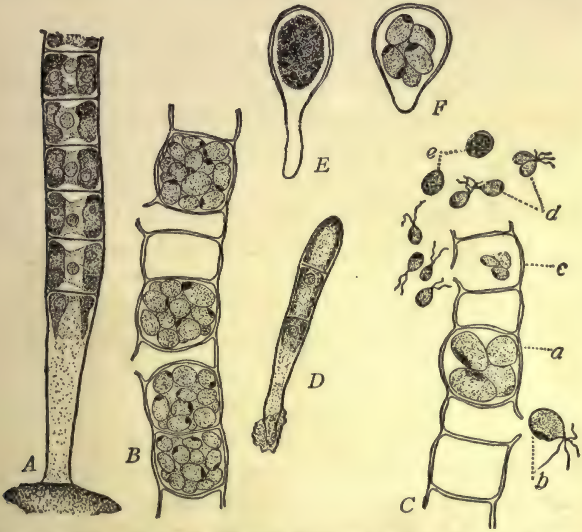

Fig. 97.—*Ulothrix: A*, base of filament, showing holdfast cell and five vegetative cells, each with a single conspicuous cylindrical chloroplast (seen in section) surrounding a nucleus; *B*, four cells containing swimming spores; *C*, one cell containing four swimming spores (*a*), a free swimming spore (*b*), a cell (*c*) from which most of the gametes have escaped, pairing gametes (*d*), and the resulting oöspores (*e*); *D*, young filament from a swimming spore; *E*, oöspore growing after rest; *F*, oöspore producing swimming spores.—*E* and *F*, after Dodel-Port.

drical chloroplast appears as a thick green mass on each side of the central nucleus (Fig. 97, *A*). Each cell is able to divide, and so the filament grows in length; or fragments of old filaments may develop new ones, resulting in vegetative multiplication.

Although each cell of the filament is an ordinary nutritive cell, under certain conditions one or more of these cells contain other cells, that have been formed by what is called the internal division of the older one (Fig. 97, *B*). In ordinary cell-division the wall of the old cell forms a part of the walls of the two new cells; but in internal division the wall of the old cell is only a case which encloses the new ones, and from which they escape. When these cells formed by internal division escape from the mother-cell into the water, it is discovered that they are able to swim about by the lashing movements of four cilia that appear in a cluster at the pointed end (Fig. 97, *C*, *b*). After a time these swimming cells settle down, lose their cilia, and by division begin the development of new filaments like those from which they came (Fig. 97, *D*). It is evident that the swimming cells have introduced a new method of reproduction—a method that involves the formation of a special cell for reproduction, quite distinct from the ordinary nutritive cells. A special cell thus set apart for reproduction is called a *spore*, and spores that swim are distinguished as *swimming spores*. A very important fact about *Ulothrix*, therefore, is that it reproduces not only by vegetative multiplication, but also by swimming spores.

In other cells of the same filaments, or in cells of filaments under different conditions, the same formation of cells by internal division may be observed; but the contained cells are smaller and more numerous (Fig. 97, *C*, *c*). When they escape, it is discovered that they also are ciliated swimming cells; but since they do not produce new filaments, it is evident that they are not swimming spores.

It has been observed that these small swimming cells come together in pairs and fuse (Fig. 97, *C*, *d*), each pair thus forming one new cell (Fig. 97, *C*, *e*). The cell thus formed passes through a resting period (usually during winter), then begins to grow (Fig. 97, *E*), and finally produces four swimming spores (Fig. 97, *F*), each of which is able to produce a new filament of *Ulothrix*. Here is evidently a third method of reproduction, which is peculiar in the fact that two special cells unite to form the spore that produces the new plant. These two special cells are *gametes* (sexual cells); their act of fusion is *fertilization;* the spore thus formed is the *oöspore* (egg-spore); and this kind of reproduction is called *sexual reproduction.** It should be observed that the swimming spores and the oöspores of *Ulothrix* do not differ in what they are able to do, but in the method of their formation, one being formed by cell-division and the other by cell-fusion; but to distinguish reproduction by spores from sexual reproduction by oöspores, the former is called *asexual reproduction*, and the spores are often spoken of as *asexual spores;* although when the word "spore" is used it generally implies an asexual spore.

The three methods of reproduction found in *Ulothrix* may be summarized in the following graphic way:

(1) Vegetative multiplication is indicated by *P*—*P*—*P*—*P*—, in which *P* stands for the plant, there being a succession of plants arising directly one from the other without the interposition of any special cells.

(2) Reproduction by asexual spores is indicated by *P*—o—*P*—o—*P*—o—*P*—, indicating that new plants are not produced directly from the old ones, but that between the successive generations there is the asexual spore.

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* It does not seem wise to multiply terms at this point, and hence the more general terms "fertilization" and "oöspore" are used as including the more special terms "conjugation" and "zygospore."

(3) Sexual reproduction is indicated by

$$P\left\{\begin{matrix}-o\\-o\end{matrix}\right\rangle o-P\left\{\begin{matrix}-o\\-o\end{matrix}\right\rangle o-P\left\{\begin{matrix}-o\\-o\end{matrix}\right\rangle o-P,$$

indicating that two special cells (gametes) are produced by the plant, that these two fuse to form one (oöspore), which then produces a new plant.

66. **Cladophora.**—This plant is found attached to sticks and stones at the edge of ponds or lakes, and is often so abundant as to form thick mats of long anchored filaments. It is easily distinguished from *Ulothrix*, for it is a much coarser plant and branches freely (Fig. 98). It is mentioned here both because it is common and because it illustrates a branching filamentous body. Just as in *Ulothrix*, reproduction in *Cladophora* is carried on by means of swimming spores, and also by the fusion of swimming gametes to form oöspores.

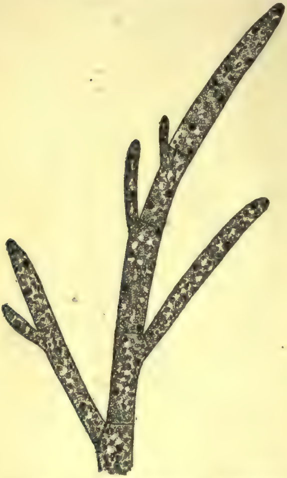

Fig. 98.—*Cladophora:* a branching filament, each of whose cells contains several nuclei.

67. **Œdogonium.** — The filaments of *Œdogonium* are long and simple, the lowest cell acting as a holdfast, as in *Ulothrix* and *Cladophora*. In each cell a nucleus may be seen (Fig. 99), and apparently several chloroplasts; but really there is only one large complex chloroplast.

Any one of these cells may produce within itself a single large swimming spore, which escapes from the mother-cell into the water (Fig. 99, *C*). At its more pointed clear end there is a little crown of cilia, by means of which it swims about rapidly. These spores finally anchor themselves, and each one produces a new filament (Fig. 99, *D* and *E*).

Certain cells of the filament become very different from the ordinary cells, enlarging and becoming globular (Fig. 99, *A* and *B*). In each one of these spherical cells there is

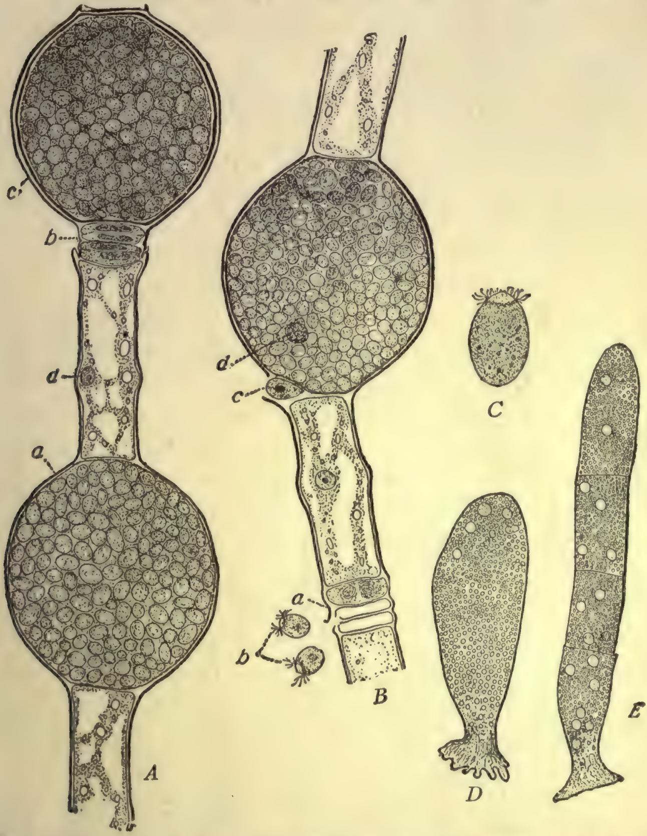

FIG. 99.—*Œdogonium: A*, portion of filament showing vegetative cell with its nucleus (*d*), an oögonium (*a*) filled by a large egg packed with food, a second oögonium (*c*) containing an oöspore, as shown by heavy wall, and two antheridia (*b*), each containing two sperms; *B*, portion of filament showing antheridia (*a*), from which two sperms (*b*) have escaped, a vegetative cell with its nucleus, and an oögonium which a sperm has entered (*c*), and whose egg nucleus (*d*) may be seen; *C*, swimming spore; *D* and *E*, young filaments developing from swimming spores.

formed a single large gamete, which remains in the cell that produces it. This large gamete, which remains passive, is the female gamete or *egg*, and the globular cell that produces it is the *oögonium* (egg-case). In the figure (Fig. 99, *A* and *B*) these large eggs are seen packed with roundish masses of reserve food.

Other cells, either in the same filament or in some other filament, differ from the ordinary cells in being much shorter (Fig. 99, *A*, *b*, and *B*, *a*). In each of them one or two gametes are formed and are set free, swimming about like small swimming spores (Fig. 99, *B*, *b*). These active gametes are the male gametes or *sperms*, and the short cell that produces them is the *antheridium*.

The sperms swim actively about in the vicinity of an oögonium, and sooner or later one enters through an opening in the oögonium wall and fuses with the egg (Fig. 99, *B*, *c*). As a result of this act of fertilization an oöspore is formed that soon organizes a firm wall about itself (Fig. 99, *A*, *c*). This firm wall indicates that the oöspore is not to germinate immediately, but is to be protected through an unfavorable season, such as failure of food supply, cold, or drought.

It is evident, therefore, that although both the swimming spores and the oöspores are able to produce new plants, the former germinate immediately and enable the plant to spread during the growing season, while the latter last through the winter when the parent plants have perished, and form new plants in the new growing season.

The most important fact illustrated by *Œdogonium* is that the gametes are not alike, as in *Ulothrix* and *Cladophora*, but have become very unlike. One of them (the egg) is relatively large and passive; the other (the sperm) is relatively small and active. In this case, therefore, the two sexes are apparent, and we recognize male and female gametes.

68. Vaucheria.—This is one of the most common of the green Algæ, occurring in felt-like masses of coarse filaments in shallow water and on muddy banks, and also commonly found on the damp earth and pots of greenhouses. It is often called green felt. The filament is very long and usually branches extensively; but its great peculiarity is that there is no partition wall in the whole body, which forms one long continuous cavity. This cavity is full of cytoplasm, and embedded in the cytoplasm are very numerous chloroplasts and also numerous nuclei (Fig. 100). Such a body, containing nuclei not separated from each other by cell-walls, is called a *cœnocyte* (common cell), or it is said to be *cœnocytic.*

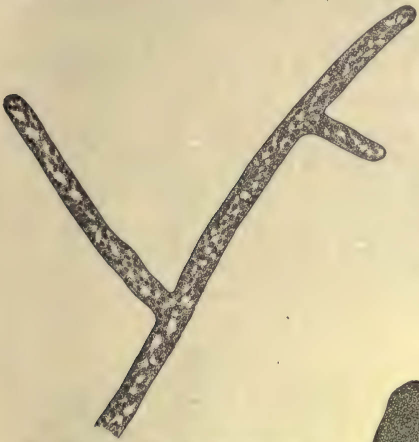

Fig. 100.—*Vaucheria:* showing the large, branching, cœnocytic, filamentous body, containing numerous chloroplasts and nuclei.

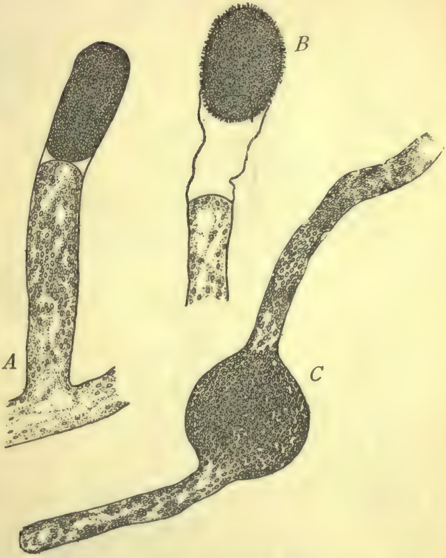

Fig. 101.—*Vaucheria:* showing the formation of the large spore (A), its discharge (B), and the beginning of a new filament (C).

Vaucheria produces very large asexual spores. The tip of a branch becomes separated from the rest of the body by a wall (Fig. 101, *A*). In this improvised chamber the whole of the contents form a single large spore. It escapes into the water through an opening in the wall, (Fig. 101, *B*) and finally develops a new filament (Fig. 101, *C*).

Sex organs (antheridia and oögonia) are also developed. In a common form of *Vaucheria* they appear separately on the side of the large cœnocytic body, and are separated from the general cavity by walls. The oögonium is a globular cell (Fig. 102, *b*), usually with a perforated beak for the entrance of sperms (Fig. 102, *f*), and contains a single large egg. The antheridium is a much smaller cell, on the end of a branch (Fig. 102, *a*), within which numerous very small sperms are formed. The usual escape into the water and entrance into the oögonium is followed by fertilization (one sperm fusing with the egg), which results in an oöspore. The oöspore develops a thick wall and is thus protected until the next growing season (Fig. 102, *c*). In another species,

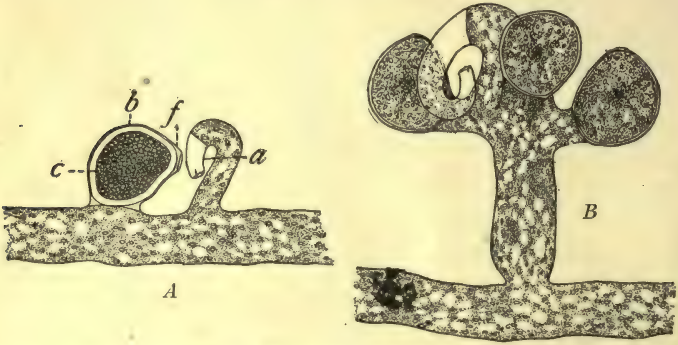

FIG. 102.—Sexual reproduction in *Vaucheria: A*, a single antheridial branch with an empty antheridium (*a*) at its tip, and also an oögonium (*b*) containing a heavy-walled oöspore (*c*) and showing the beak (*f*) through which the sperm passed; *B*, another species, in which a single branch bears several oögonia, and a terminal coiled antheridium.

often more abundant, a single branch from the main body bears several lateral oögonia and a terminal coiled antheridium (Fig. 102, *B*).

The two important facts illustrated by *Vaucheria* are the cœnocytic body and the development of special cells to act as sex organs.

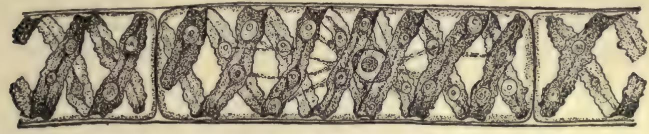

Fig. 103.—*Spirogyra:* one complete cell, showing the spiral, band-like chloroplasts, with embedded pyrenoids, and a nucleus (near the center) swung by radiating strands of cytoplasm.

69. Spirogyra.—This is one of the most common of the pond scums, occurring in slippery and often frothy masses of delicate filaments floating in still water or about springs. The filaments are simple, and are not anchored by a special basal cell.

The cells contain remarkable chloroplasts, which are bands passing spirally about within the cell-wall (Figs. 103 and 104). These bands may be solitary or several in a cell, and form very striking and

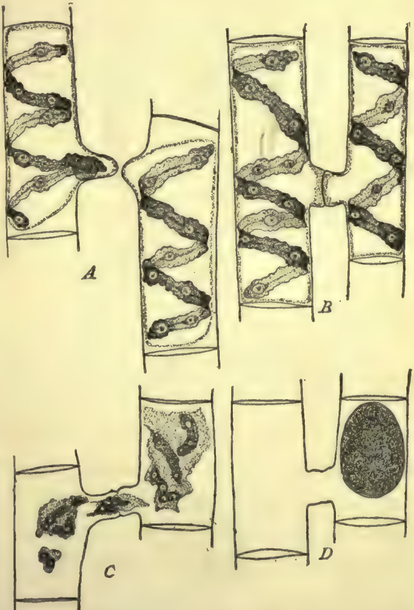

Fig. 104.—*Spirogyra: A-C*, various stages in the development of sexual tubes; *D*, a completed oöspore.

conspicuous objects. The band is not flat, and to determine its form is an excellent exercise for a student learning to reconstruct objects under the microscope. Embedded in the chlorophyll band nodule-like bodies (*pyrenoids*) are seen, around which a granular zone of starch grains is often visible. In favorable material, notably cells with a single band, the nucleus may be seen, surrounded by a zone of cytoplasm that is connected by radiating strands with the cytoplasm against the wall (Fig. 103).

Spirogyra is peculiar in producing no swimming spores, or asexual spores of any kind. Its method of sexual reproduction also is peculiar. Cells of two adjacent filaments put out protuberances toward one another; and where they come in contact an opening is formed, the result being that there is a continuous passageway connecting a cell of one filament with a cell of the other (Figs. 104 and 105). When many of the cells of two parallel filaments become thus united, the appearance is that of a ladder, with the filaments as the side pieces and the connecting tubes as the

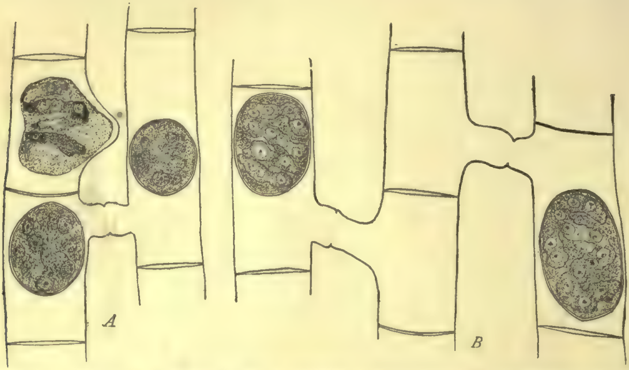

Fig. 105.—*Spirogyra*, showing some common exceptions: *A*, two connected cells that have formed oöspores without fusion, and a second cell that has attempted to connect with one of them; *B*, cells of three filaments, the cells of the central one having connected with both the others.

rounds. In each cell thus connected with another a single large gamete is formed, and one of them passes through the connecting tube to the other. The gametes are similar, and their fusion results in a heavy-walled oöspore (Fig. 104, *D*), which endures through the winter and germinates during the following season.

Plasmolysis.—Spirogyra is a very favorable form for demonstrating *plasmolysis*, which means the shrinkage of protoplasm from loss of water. The cytoplasm of an active cell is full of water, which often collects in droplets of varying size, called *vacuoles*. There is always a layer of cytoplasm in close contact with the cell-wall, but the interior of the cell may be one large vacuole traversed by strands of cytoplasm, as in *Spirogyra*. The turgor of the cell (§ 64) keeps the elastic wall distended; but if the cell be put in a solution of sugar, water will be withdrawn. The vacuoles thus beginning to lose their water, the cytoplasm shrinks; and if the loss continues, the vacuoles are obliterated, and the layer of cytoplasm in contact with the wall separates from it, all the cytoplasm of the cell contracting into a compact mass (Fig. 106). The name plasmolysis really means the "loosening" of the "plasma" (protoplasm) from the wall. Anything that withdraws water from a cell *plasmolyzes* it, and the filamentous Algæ are favorable forms for experiments to show this.

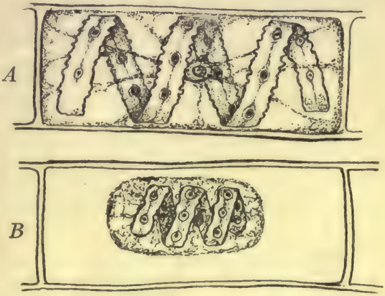

Fig. 106.—Plasmolysis: *A*, a cell of *Spirogyra* before plasmolysis; *B*, the same cell after plasmolysis with a ten per cent solution of salt.

70. **Conclusions.**—The green Algæ are so named because the green of the chloroplasts is neither modified nor obscured

by other colors, and the plants have a characteristic grass-green color. As indicated by the illustrations given above, they include simple one-celled forms which reproduce only by cell-division (vegetative multiplication), and simple or branching filamentous forms which also reproduce by swimming spores and oöspores. Such filamentous forms as *Ulothrix*, *Cladophora*, and *Œdogonium* are representatives of a group known as the *Conferva* forms, having bodies of many cells and swimming spores. *Vaucheria* represents the large group of *Siphon* forms, characterized by their cœnocytic bodies. *Spirogyra* represents the *Conjugate* forms, the name meaning "yoked together," and referring to the connecting of the filaments for fertilization; the group is characterized also by the absence of swimming spores and the peculiar chloroplasts, not all of which are spiral bands.

The bodies of green Algæ are not all single cells or filaments, the marine sea-lettuces, belonging with the *Conferva* forms, having broad, flat, leaf-like bodies that have suggested the common name. Some of the green Algæ are associated with the blue-green Algæ in the pollution of water reservoirs referred to in § 62.

3. BROWN ALGÆ (*Phæophyceæ*).

71. General characters.—The two preceding groups are the most common Algæ of the fresh waters, but the brown Algæ are almost all of them marine. The association of a brown coloring matter with the chlorophyll has given name to the group, and the plant bodies display various shades of yellow, brown, or olive. In size the brown Algæ range from forms that are microscopic to those that are hundreds of feet long. They belong chiefly to the colder waters of the globe, reaching their greatest development in the arctic and antarctic regions. The greatest displays of huge bodies along our own coasts are to be found on the rocky shores of the North Atlantic and the North Pacific, the display on the latter coast being especially rich in forms. They are all anchored plants, the strong holdfasts and leathery bodies enabling them to live exposed to strong waves and currents.

The largest forms are the kelps (Laminarias), the general habit of body being a stem fastened to the rocks by a cluster of strong, root-like holdfasts, and ending in a blade-like expansion (Fig. 107). The giant kelps of the Pacific Coast are the most notable forms. One of these has a stem about as large as a clothes-line, reported as sometimes reaching a length of 900 feet, and bearing numerous leaves (Fig. 108). The bladder kelp has a very long flexible stem (120 to 150

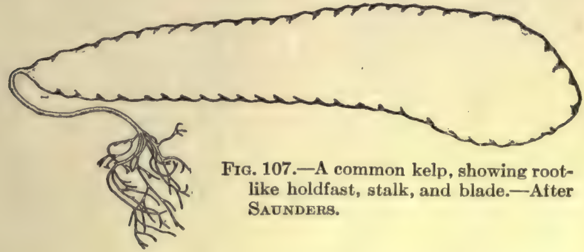
FIG. 107.—A common kelp, showing root-like holdfast, stalk, and blade.—After SAUNDERS.

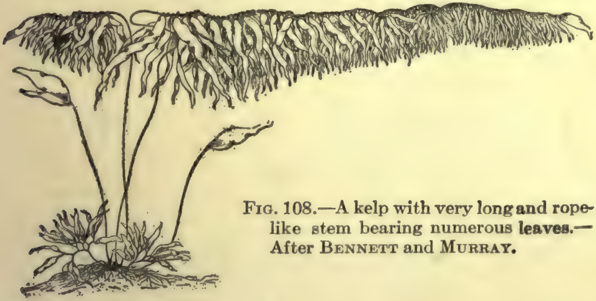
FIG. 108.—A kelp with very long and rope-like stem bearing numerous leaves.—After BENNETT and MURRAY.

feet) that swells at the end into a large globular float, to which are attached leaves often ten or twelve feet long (Fig. 109). The sea-palm has a thick erect stem that bears a crown of large drooping leaves (Fig. 110).

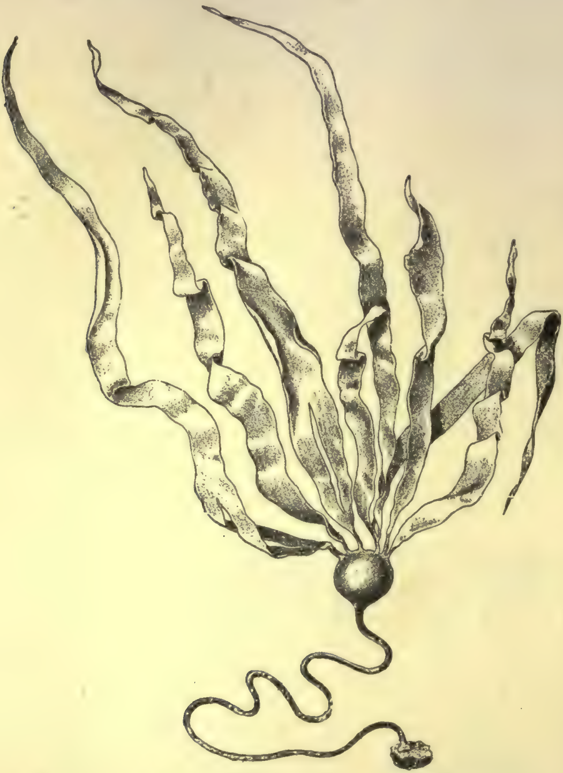

FIG. 109.—A bladder kelp.—After POSTELS and RUPRECHT.

Another group of brown Algæ is represented by the rockweeds (called also wrack) and the gulfweeds. The former (mostly *Fucus*) cover the rocks between tide-marks, being ribbon-like forms repeatedly forking at the swollen tips and often bearing air-bladders to assist in floating (Fig. 111). The most complex body is that of the gulfweed (*Sargassum*), in which there are slender branching stems

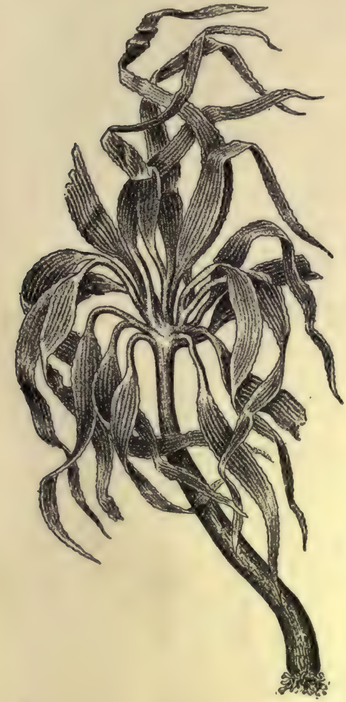

Fig. 110. — A sea-palm. — After Ruprecht.

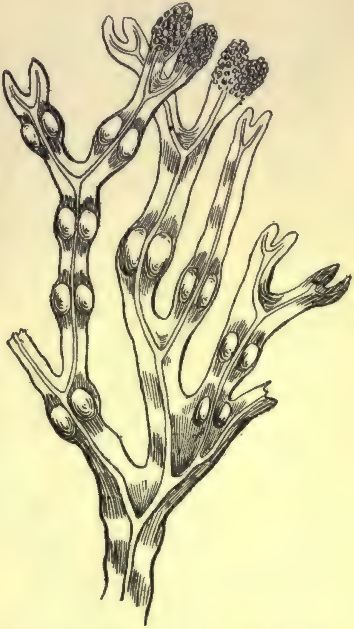

Fig. 111.—Fragment of *Fucus*, showing forked branching, reproductive tips, and air-bladders.—After Luerssen.

bearing numerous leaves like ordinary foliage, and stalked air-bladders that resemble berries (Fig. 112). The gulfweeds occur in warmer waters than do the other large forms, and are often torn from their anchorage and carried away from the coast by currents, collecting in the great sea eddies produced by oceanic currents and forming the so-called Sargasso seas. Some of the gulfweeds forming these masses of vegetation floating in mid-ocean continue to grow luxuriantly, especially in warmer parts of the Atlantic.

From the ashes of kelps and rockweeds the chief supply of iodine is obtained; and these great masses of vegetation, thrown up or left exposed by the tides, are used for enriching farm lands.

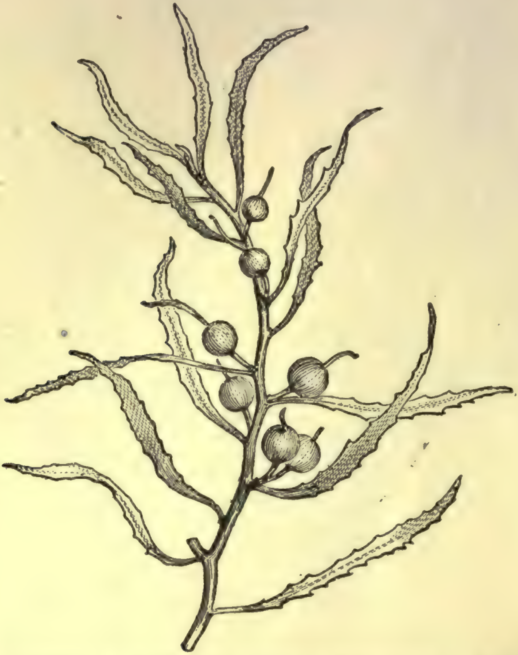

Fig. 112.—Fragment of *Sargassum*, showing differentiation of the thallus into stem-like and leaf-like portions, and also the bladder-like floats.—After Bennett and Murray.

72. **Ectocarpus.**—The two principal groups of brown Algæ are distinguished from each other by their reproduction. By far the larger group includes the kelps, whose method of reproduction is very simple, although many

of their bodies are huge. *Ectocarpus* may be used to illustrate the essential features of the group. Its body is filamentous (Fig. 113), suggesting the body of some of the *Conferva* forms among the green Algæ. Certain cells of the filament (Fig. 113, *A*), or the end cells of special short branches, become enlarged and produce numerous swimming spores. The swimming spores of brown Algæ are peculiar in usually bearing the two cilia on one side of the body rather than at one end, and hence they are described as laterally biciliate (Fig. 115, *G*).

The cell that produces swimming spores was sometimes spoken of among the green Algæ as a mother-cell, but a mother-cell may not always produce spores. Hence it is well to use a term that implies the product of the mother-cell, and in this case the term is *sporangium* (spore-case). A sporangium, therefore, is an organ that produces spores; and among the Algæ described thus far it consists of one cell.

In addition to the one-celled sporangia, other organs in similar positions may occur; but they differ from the sporangia in being many-celled (Fig. 113, *B*). In each cell usually one body is formed, which when discharged is seen

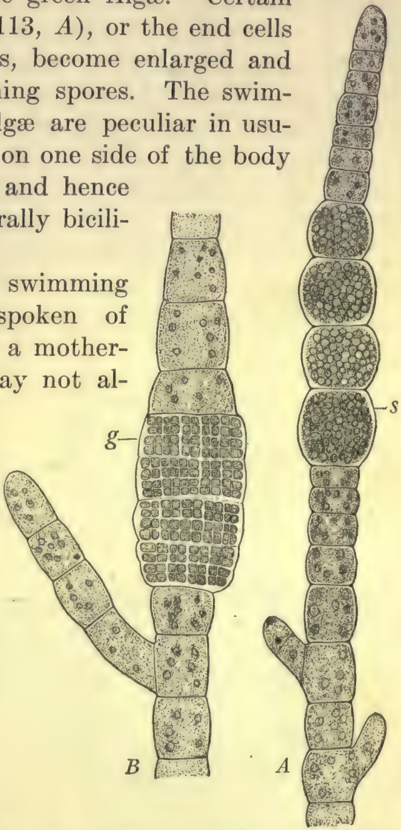

FIG. 113.—*Ectocarpus:* a filamentous, branching form: *A*, filament bearing one-celled sporangia (*s*); *B*, filament bearing many-celled gametangia (*g*).

to resemble the swimming spores. However, it fuses with another cell of the same kind, and this behavior and the result show that it is a gamete. As a result of this act of fertilization an oöspore is formed, as in the case of *Ulothrix* (§ 65). This kind of sexual reproduction is regarded as simple because the pairing gametes are alike, and have not become distinguished as egg and sperm, as in *Œdogonium* (§ 67) and *Vaucheria* (§ 68). In those plants separate names were given to the organs producing eggs (oögonia) and those producing sperms (antheridia). In *Ulothrix* and *Ectocarpus*, on the other hand, no such distinction can be made, and hence the organ producing gametes is called a *gametangium* (gamete-case). Of course oögonia and antheridia are gametangia, but the latter name is generally used only when the gametes are alike. In *Ectocarpus*, therefore, many-celled gametangia are produced (Fig. 113, *B*), in addition to one-celled sporangia (Fig. 113, *A*).

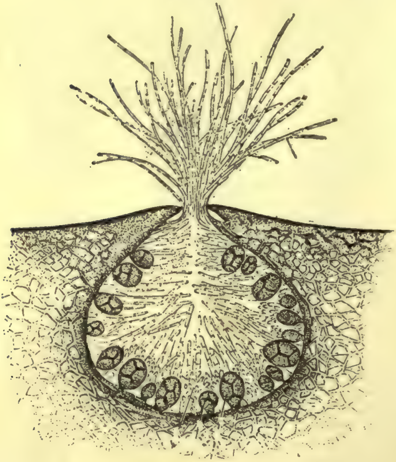

FIG. 114.—*Fucus:* showing a section of the cavity (conceptacle) containing the sex-organs, in this case only oögonia.—After THURET.

This great group of brown Algæ, of which *Ectocarpus* is here used as a representative, is distinguished, therefore, by its swimming spores and its similar gametes.

73. **Fucus.**—The smaller group of brown Algæ comprises the rockweeds (*Fucus*) and the gulfweeds (*Sargassum*), the former of which may be used to illustrate the group.

In the swollen and forked tips (Fig. 111) of the ribbon-like body of *Fucus* numerous flask-shaped cavities occur, each of which communicates with the surface by a

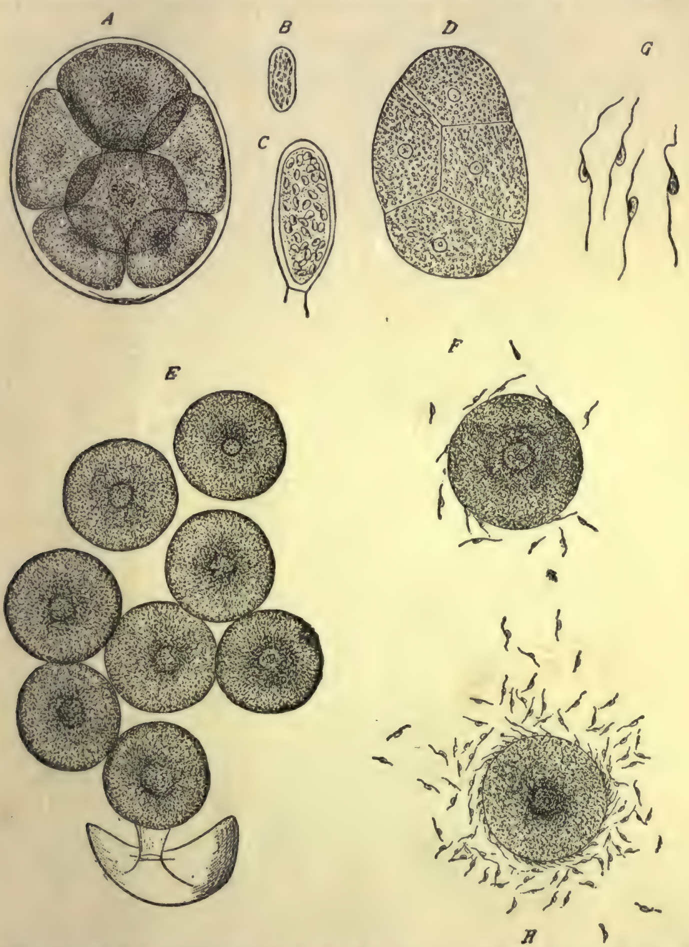

FIG. 115.—*Fucus:* showing eggs in the oögonium (*A*) and after discharge (*E*), antheridium containing sperms (*C*), the discharged laterally biciliate sperms (*G*), and eggs surrounded by swarming sperms (*F* and *H*).—After STRASBURGER.

small, pore-like opening (Fig. 114). On the walls of these cavities oögonia and antheridia are produced. The oögonium is peculiar in that it usually produces eight eggs, which are discharged and float free in the water (Fig. 115, *A* and *E*). About these eggs the sperms swim in great numbers, often striking against them and setting them rotating (Fig. 115, *F* and *H*). Finally, a single sperm fuses with an egg and an oöspore is formed, which later produces a new *Fucus* plant.

This group of brown Algæ, therefore, differs from the other one in producing no swimming spores, and in its dissimilar gametes (eggs and sperms).

4. Red Algæ (*Rhodophyceæ*).

74. General characters.—The red Algæ are mostly marine forms, and receive their name from the fact that a red coloring matter completely masks the chlorophyll. As a consequence, the plants are various shades of red,

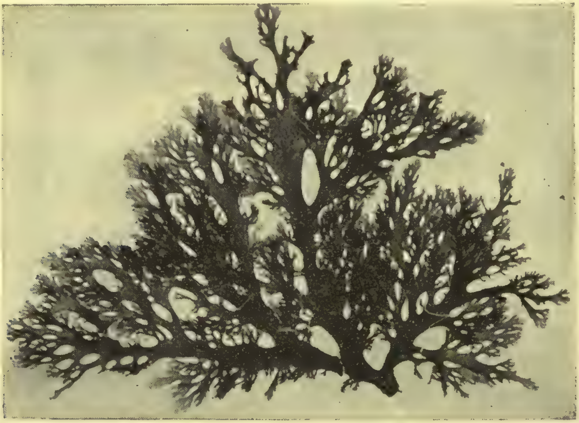

Fig. 116.—One of the red Algæ.

violet, dark purple, and reddish-brown, often beautifully tinted. In general, the bodies are much more graceful and delicate than those of the brown Algæ. There is the

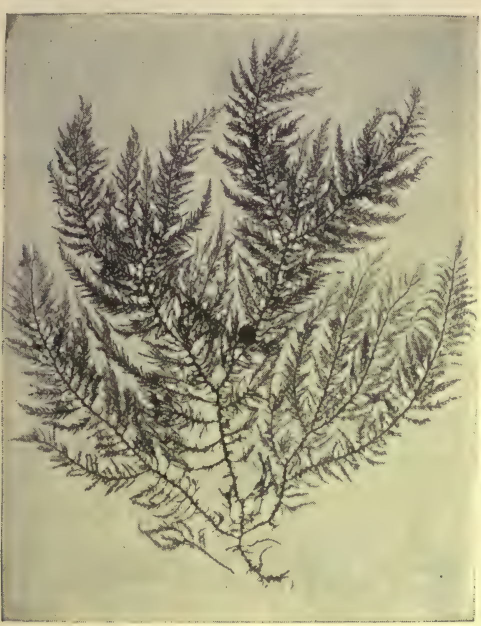

FIG. 117.—One of the red Algæ.

greatest variety of forms, branching filaments, ribbons, and filmy plates prevailing; and often profuse branching occurs, the plants resembling mosses of delicate texture (Figs. 116 and 117). One remarkable group, chiefly displayed on tropical and surf-beaten coasts, contains such a deposit of lime in the cell-walls that the forms resemble branching corals or coral-like incrustations; and for this reason they are called corallines.

Red Algæ are all anchored forms, and are chiefly displayed in temperate and tropical waters. While not restricted to any special depth, they are characteristic of the deeper waters in which Algæ grow. The red Algæ are very little used by man, probably the most conspicuous article of commerce obtained from them being Irish moss, used in jelly-like preparations, which is the dried bodies of certain forms abundant in the North Sea.

75. **Reproduction.**—The reproduction of the red Algæ is very peculiar, being entirely unlike that of the other Algæ. No swimming spores are produced, but sporangia occur that produce and discharge spores without cilia and hence without the ability to swim. Since each sporangium usually produces four such spores, they are called *tetraspores* (Fig. 118). Floating about in the water instead of actively swimming, they finally germinate and produce new plants, as do the swimming spores.

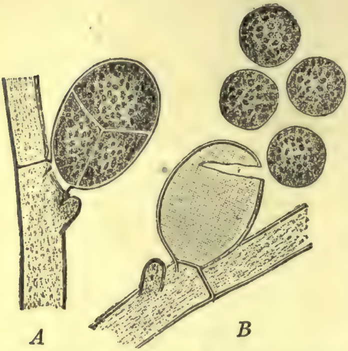

FIG. 118.—The sporangium (*A*) and discharged tetraspores (*B*) of one of the red Algæ.—After THURET.

The sexual reproduction, however, is most remarkable, but is too complex to be presented in any detail in an elementary text. The sperms, like the tetraspores, are without cilia and simply float into contact with the oögonium, whose form is like that of a flask with a long narrow neck (Fig. 119, *A*). In the bulbous base of the oögonium the egg is developed. In a very simple case the floating sperm comes in contact with the long neck, the two walls become perforated at the point of contact, the contents of the sperm enters and passes to the egg, and thus fertilization is accomplished. As a result of fertilization there appears on the plant a spore-containing structure like a little fruit (Fig. 119, *B* and *C*, and Fig. 120). The spores it contains produce the alga plants again.

Such a life-history is more complex than any thus far given. During the growing season the tetraspores multiply the plant; and the life-history may be indicated as follows, *P* designating the ordinary plant body:

P—tetraspore—*P*—tetraspore—*P*—tetraspore, etc.

Such a series, however, does not continue indefinitely; for it is stopped by the coming of an unfavorable period, such a period as winter represents to many plants. In the life-history of our red alga this unfavorable period is bridged by the fruit-like body, just as in the other Algæ it is bridged by the heavy-walled oöspore. Such

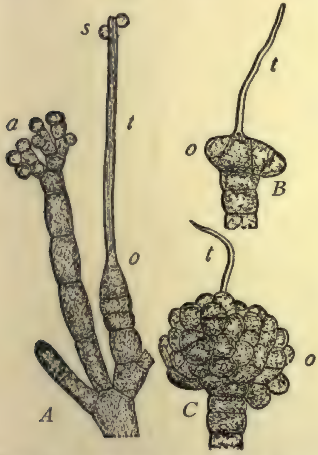

FIG. 119.—One of the red Algæ: *A*, sexual branches, showing antheridia (*a*), oögonium (*o*) with its long neck (*t*) to which are attached two sperms (*s*); *B* and *C*, development of the fruit-like body.—After KNY.

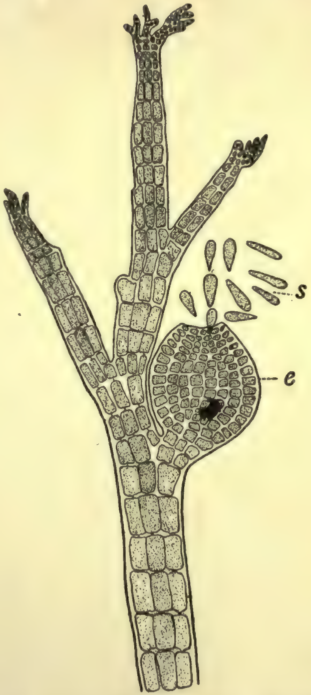

FIG. 120.—A branch of one of the red Algæ showing a mature fruit-like body (*e*), with escaping spores (*s*).

a life-history may be indicated as follows, a formula in which the fruit-like body is designated by *F:*

$$P\left\{\begin{array}{l}\text{—sperm}\\ \text{—egg}\end{array}\right\rangle F\text{—spore—}P\left\{\begin{array}{l}\text{—sperm}\\ \text{—egg}\end{array}\right\rangle F\text{—spore—}P\text{, etc.}$$

The formula shows an alternation of the ordinary plant body and the fruit-like body; the latter always resulting from the act of fertilization, and the former coming from an asexual spore. This alternation becomes a conspicuous feature of higher plants.

CHAPTER VII

FUNGI

76. General characters.—The Fungi do not contain chlorophyll, and this fact forms the sharpest contrast between them and the Algæ. The presence of chlorophyll enables the Algæ to be independent of any other organism, since they can manufacture their food out of carbon dioxide and water (§ 14). The absence of chlorophyll compels the Fungi to be dependent upon other organisms for their food. This food is obtained in two general ways: either (1) directly from living plants and animals, or (2) from organic waste products or dead bodies. In case a living body is attacked, the attacking fungus is called a *parasite;* and the plant or animal attacked, the *host.* In case the food is obtained in the other way, the fungus is called a *saprophyte.* For example, the rust that attacks wheat is a parasite, and the wheat is the host; while the mold which often develops on stale bread is a saprophyte.

In case parasites attack valuable plants or animals they may be very harmful, giving rise to destructive diseases. The United States Government has expended a great deal of money in studying such Fungi, trying to discover some method of destroying them or of preventing their attacks. There is an interesting selective power exhibited by many parasites, that restrict themselves to certain plants and animals, or even to certain organs. Many, however, are more general in their attacks; and some can live as parasites or saprophytes as occasion demands. It must not be supposed that all parasites are harmful to man or even destructive to their host.

In the case of saprophytes, dead bodies or body products are attacked, and sooner or later all organic matter is attacked and decomposed by them. Were it not for them "the whole surface of the earth would be covered with a thick deposit of the animal and plant remains of the past thousands of years."

The parasitic and saprophytic habits are not restricted to the Fungi, for they have been developed also by some of the higher plants; but by far the largest display of these habits is that given by the Fungi. It is thought that Fungi have been derived from Algæ; that is, that Fungi are simply Algæ that have learned the parasitic or saprophytic habit. Some of them resemble certain Algæ so closely that the connection seems very plain; but others have become so modified that they have lost all likeness to the Algæ.

No attempt will be made to present even an outline of the classification of this vast and perplexing group. A few illustrations will be selected from the best-known forms, especially those of importance to man.

77. **Bacteria.**—Bacteria include the smallest known living forms, some of which are spherical cells only $\frac{1}{50,000}$ inch in diameter. It is estimated that 1,500 of certain rod-shaped forms, placed end to end, would about stretch across the head of an ordinary pin. Even to distinguish ordinary bacteria, therefore, the highest powers of the microscope are necessary; and to study them is too difficult for the untrained student. However, they are so very important to man, on account of their useful and destructive operations, that every student should have some information about them. Public attention has been drawn to them chiefly on account of the part they play in many infectious diseases, in which connection they are often referred to as "microbes" or "germs."

Bacteria are found almost everywhere—in the air, in the water, in the soil, in most foods, and in the bodies of plants and animals, as regular inhabitants. Many of them are entirely harmless, some are useful, and others are very dangerous. A laboratory near Paris, arranged for studying bacteria in the air, has found that the average number of bacteria in every quart of air in that locality is eighty. The highest numbers were found during the autumn, and the lowest during the winter; while a wind from the city increased the numbers very much. The "pure" water of springs and wells contains abundant bacteria, while in stagnant water and sewer water they swarm in immense numbers. The slimy deposits usually observed about "iron" and "sulphur" springs, or in the pipes leading from them, are due to the presence of the peculiar bacteria living in such waters. The presence of dangerous bacteria in drinking water is probably the most common cause of epidemics of infectious diseases, and warnings as to the dangerous condition of a city water-supply should always be heeded. It is very evident that no sewage should find its way into such water-supply.

It is important to know something about the structure and the habits of bacteria, before considering some of their important relations to man. They are one-celled and occur in three general forms: (1) spherical cells, usually grouped in various ways, and including the minutest forms (Fig. 121, *B*); (2) rod-shaped cells, that is, longer than broad, the cells remaining separate or attached end to end and forming filaments (Fig. 121, *F* and *G*); (3) elongated cells, more or less curved, from short curved forms resembling a comma to long spirals (Fig. 121, *J*-*M*). Many bacteria swim more or less actively by means of cilia; and this fact first gave the impression that they are minute animals—an impression that is still prevalent outside of laboratories (Fig. 121).

Reproduction is by cell-division, as among the blue-green Algæ (§ 58–60), a group which the bacteria resemble in many ways. This cell-division is remarkably rapid in bacteria, resulting in such a prodigious multiplication of in-

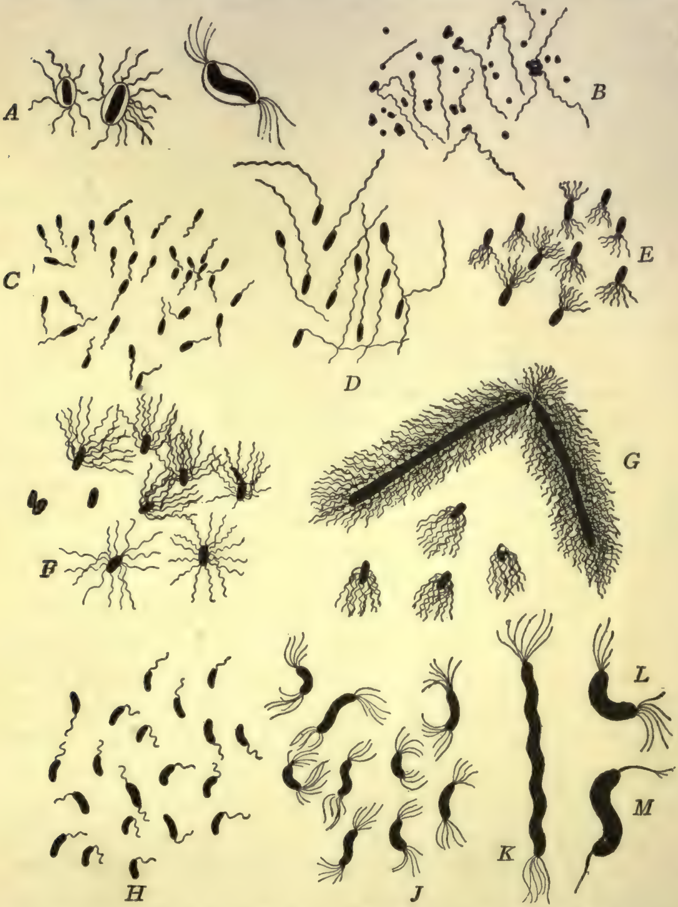

Fig. 121.—A group of bacteria of various kinds, mostly ciliated; *F* is the bacterium of typhoid fever, and *H* that of cholera.—After Engler and Prantl.

dividuals in a comparatively short time that it is impossible to imagine what would happen if bacteria were left free to reproduce to their full capacity. Bacteria have been observed to reproduce themselves in fifteen to forty minutes after their formation; that is, a single generation of such bacteria is that length of time. It would be interesting to determine the number of progeny from a single bacterium at the end of twenty-four hours, if such a rate were maintained. When nutrition fails, many bacteria have the power of passing into a protected condition, a portion of the protoplasm within the cell separating from the rest and becoming surrounded by a thick membrane (Fig. 122). The rest of the cell finally disorganizes and this internally formed cell persists. It has received the name of "spore," but is not to be regarded as a spore in the usual sense. A single bacterium produces only one such spore, and when this spore again encounters favorable conditions it produces in turn only a single bacterium. This "spore," therefore, is only an inactive and protected condition of the bacterium.

It is of great importance to determine the power of resistance of bacteria and of their more resistant "spores," and there is great variation in this regard. Drying and cold kill many, but not all. For example, it is known that the bacterium of typhoid fever (Fig. 121, *F*) can endure freezing in a block of ice for months and become active again when the ice melts; and for this reason the source of ice used in drinking water should be considered as carefully as the source of the water itself. Moist heat, however, as boiling or steaming, has been found to be most efficient in killing bacteria; and so the boiling of water and the cooking of food are usually ample safeguards against them. The so-called disinfectants are chemicals that destroy bacteria. It is the knowledge of such facts that has developed what is called antiseptic surgery, which is the use of various means to exclude bacteria and so prevent inflammation and decay.

The most important relations of bacteria to man may be grouped under the following three heads: (1) those that *induce fermentation;* (2) those that *induce disease;* (3) and those that *fix nitrogen.*

(1) *Bacteria that induce fermentation.*—In general, fermentation is the decomposition of carbohydrates and proteids by the action of living forms directly or by the enzymes (§ 47) which they produce, and conspicuous among these forms are bacteria. When proteids (meat, etc.) containing nitrogen and sulphur are decomposed in this way, offensive gases are liberated, such decomposition being often called putrefaction. When the word fermentation is ordinarily used it refers to the decomposition of sugars in solution, as in various fruit juices, which breaks them up into alcohol and carbon dioxide, the latter rising as bubbles through the solution, which is then said to be working. Such fermentations are produced chiefly by yeasts, which are considered in the next section; but bacteria are concerned in the souring of milk and of fruit juices and in the manufacture of vinegar (Fig. 122). These saprophytic bacteria that induce fermentation and putrefaction are of much service as scavengers, being the chief agents in the destruction of dead bodies. The various processes for

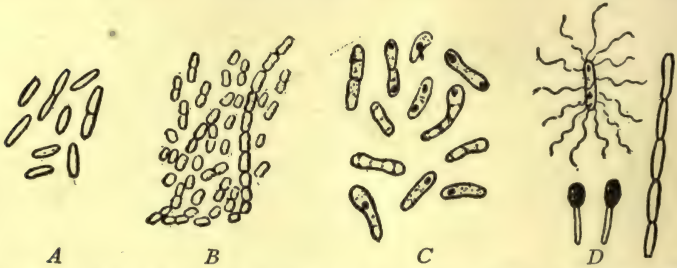

FIG. 122.—Certain bacteria of fermentation and disease: bacteria of souring milk (*A*), of vinegar (*B*), of diphtheria (*C*), of tetanus or lockjaw (*D*); *C* and *D* show the formation of the so-called "spore."—After FISCHER.

preserving food are attempts to exclude bacteria that would induce fermentation or decay.

(2) *Bacteria that induce disease.*—Fortunately most bacteria are harmless, for they are constantly present in the nostrils and mouth and alimentary tract. Even those that are dangerous may be resisted successfully and fail to develop any symptoms of disease. When the resistance has been ineffectual and the disease has developed, the bacteria may produce local effects, as in diphtheria (Fig. 122, *C*) and in typhoid fever (Fig. 121, *F*); but the most general effect is from the production of poisons (toxins) which are distributed by the blood, leading to fever, delirium, etc. These poisons are different for each disease, so that a successful antidote (antitoxin) for the diphtheria poison has no effect on the poison of the bacterium of typhoid fever. It is hoped that antitoxins will be discovered for all such bacterial diseases, among which are not only diphtheria and typhoid fever, but also cholera (Fig. 121, *H*), tuberculosis, and pneumonia. Such eruptive diseases as measles and scarlet fever have not yet been proved to be due to bacteria. Among plants also certain bacterial diseases occasion great loss, as pear blight and peach yellows, and as yet have baffled those seeking for remedies.

(3) *Bacteria that fix nitrogen.*—It will be remembered that green plants manufacture carbohydrates from carbon dioxide and water (§ 14); but that in the manufacture of proteids from carbohydrates nitrogen is necessary. Although free nitrogen constitutes nearly eight-tenths of the air, plants cannot use it in that form, but must obtain it through their roots from certain compounds existing in the soil. As crops are removed, the nitrogen supply in the soil is diminished, and presently the soil becomes so impoverished that it is said to be exhausted. To restore the fertility of the soil, the farmer has learned to use nitrogen-containing fertilizers. Through the removal of crops and

in various other ways the loss of available nitrogen for plants is enormous; and to meet this loss is one of the most important problems, for the known sources of suitable fertilizers cannot yield them for very many years.

Since an endless supply of free nitrogen exists in the air, it is natural to turn to this source of nitrogen supply for plants. This means that the free nitrogen of the air must be "fixed" in some combination that can be used by plants. It is just here that bacteria of the soil play a very important part. Not only do those bacteria that produce fermentation and decay lay hold of plant and animal bodies and produce the necessary nitrogen-containing substances in the soil, but certain other bacteria of the soil have the power of fixing the free nitrogen of the air into compounds, and hence they are called "nitrogen-fixing bacteria." If worn-out land lies fallow for a few years there will be a slow accumulation of nitrogen salts through the activity of these bacteria. They have been cultivated artificially, and it is hoped that such cultures will be obtained that it may be possible to use them to inoculate impoverished land with nitrogen-fixing bacteria and so hasten its restoration.

A peculiar group of soil bacteria penetrates the roots of certain leguminous plants, as clover, alfalfa, peas, beans, etc., and produces little wart-like outgrowths known as *root-tubercles* (Fig. 123). The cells of the tubercles swarm with bacteria, which are found to have the power of fixing the free nitrogen of the air circulating in the soil. As a consequence, such plants can live and thrive in a soil exhausted of its nitrogen salts, and can be used in restoring the soil. After an ordinary crop, such as wheat, has exhausted the soil, a crop of clover or of alfalfa plowed under will restore such an amount of nitrogen salts to the soil that it can be used again for wheat, often with a surprising yield. This indicates the significance of what is called rotation of crops.

It is a very interesting and important fact that these root-tubercle bacteria have been cultivated artificially at the United States Department of Agriculture in such a way that they can be shipped anywhere at small cost and used to inoculate soils that are deficient in tubercle-forming bacteria. This deficiency may be discovered either by the ab-

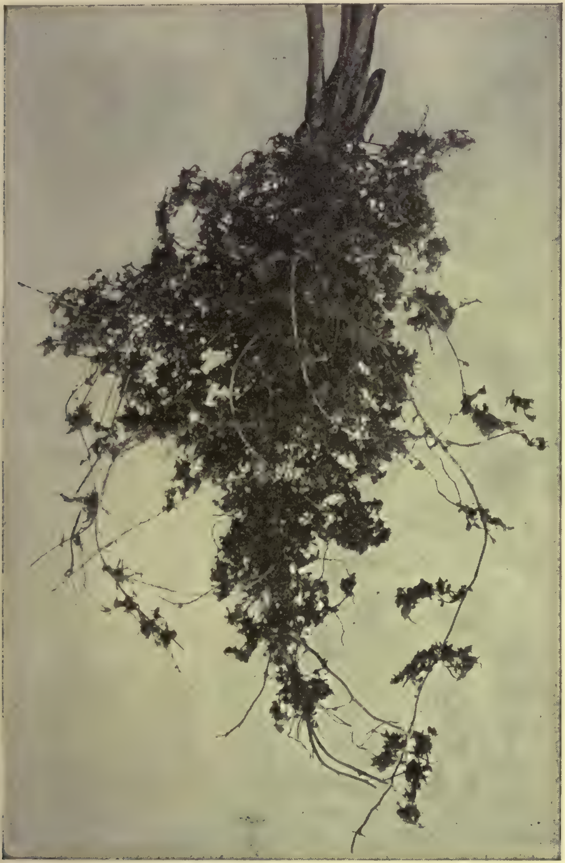

Fig. 123.—Root-tubercles on sweet clover.

sence of tubercles on the roots of leguminous plants or by the failure of such plants to grow at all.

78. **Yeasts.**—Yeasts are one-celled plants that reproduce by *budding.* This curious method consists in a cell's putting out one or more projections which gradually enlarge and finally become pinched off. Often the cells thus produced cling together in short irregular chains (Fig. 124). The chief interest in connection with yeasts is the important part they play in the fermentation of sugar solutions, "splitting" the sugar into alcohol and carbon dioxide, a process also induced by certain bacteria (§ 77), but chiefly by the yeasts. Fermentation by yeasts is employed on a large scale in the manufacture of beer, wine, and spirits, and in the making of bread. In the last-named process, the dough is inoculated with yeast plants and placed in a sufficiently warm temperature to induce rapid growth. The plants begin to reproduce actively by budding; the sugar in the dough is split into alcohol and carbon dioxide; and the latter, being a gas, expands and puffs up the dough, making it light and porous, that is, causing it to "rise."

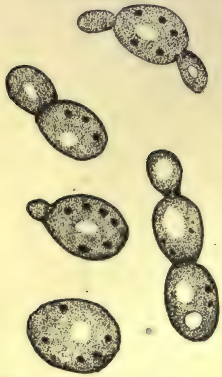

FIG. 124.—Yeast-cells, reproducing by budding, and forming chains.

The yeasts commonly used have been cultivated for centuries and are not known in the wild state. There are also "wild yeasts" of many kinds, and many spores of the higher Fungi behave like the yeasts in budding and inducing fermentation. The "working" of yeast may be demonstrated by introducing some of the yeast preparations into a solution of sugar or sirup and setting it in a warm place. After a few hours the bubbles of carbon dioxide should be seen rising through the liquid.

79. Mucor.—One of the most common of the Mucors, or black molds, forms white furry growths on damp bread, preserved fruits, manure heaps, etc. It may be grown easily

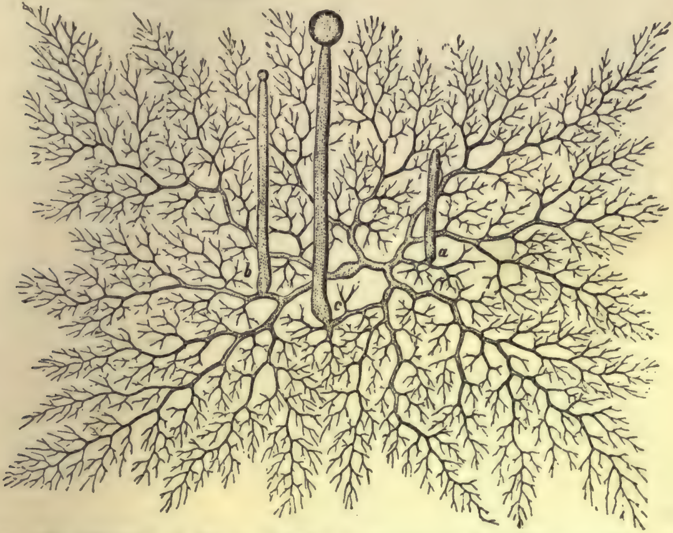

FIG. 125.—Diagram of *Mucor*, showing the profusely branching mycelium and three sporophores, sporangia forming on *b* and *c*.—After ZOPF.

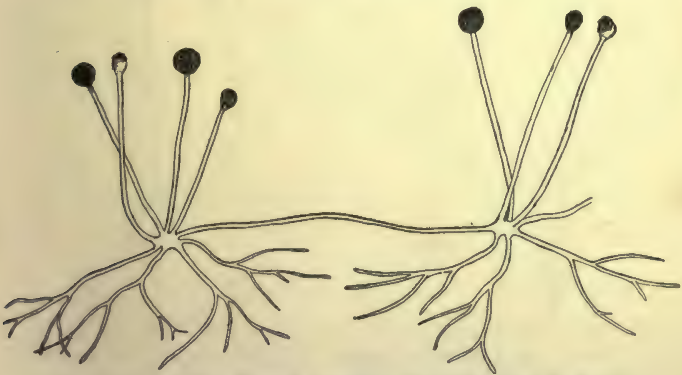

FIG. 126.—Diagram showing mycelium and sporophores of *Mucor*.

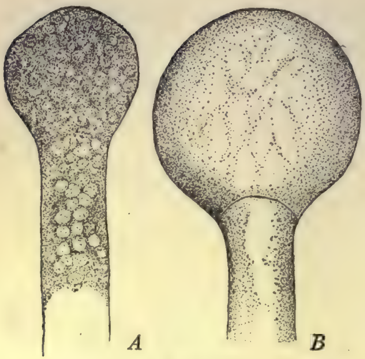

FIG. 127.—Developing sporangia of *Mucor:* *A*, swollen tip of sporophore; *B*, wall separating sporangium from the rest of the body.

by keeping a piece of moist bread in a warm room under a glass vessel. The sources of its food supply indicate that it is a saprophyte.

The body of *Mucor* is a good illustration of the bodies of ordinary Fungi. The principal part of the body consists of colorless branching threads, either isolated or more often interwoven, and is called the *mycelium* (Fig. 125). The interweaving may be very loose, the mycelium looking like a delicate cobweb; or it may be close and

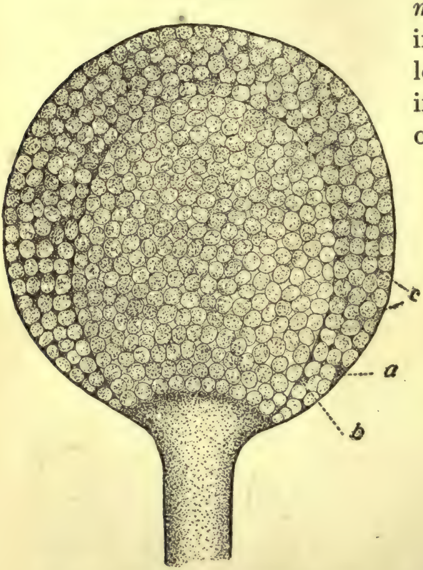

FIG. 128.—Mature sporangium of *Mucor*, showing wall (*a*), numerous spores (*c*), and partition wall pushed up into the cavity of the sporangium (*b*).

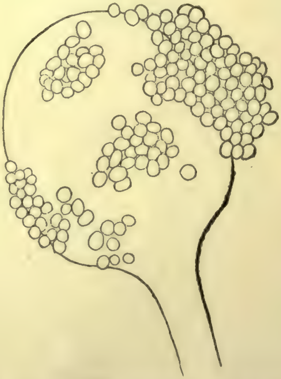

FIG. 129.—Burst sporangium of *Mucor*, the ruptured wall not being shown, the loose spores adhering to the convex partition wall (see Fig. 128).

compact, forming a felt-like mass, as may be seen sometimes in connection with preserved fruits. The mycelium is in contact with its source of food-supply, which is called the *substratum.*

From the prostrate mycelium numerous erect branches arise, each branch bearing at its tip a large globular cell containing spores (Figs. 126, 127, 128). The globular cell, therefore, is a sporangium, and the erect branch is a sporophore (spore-bearer). The sporangium wall bursts (Fig. 129), the light spores are scattered by the wind, and fall-

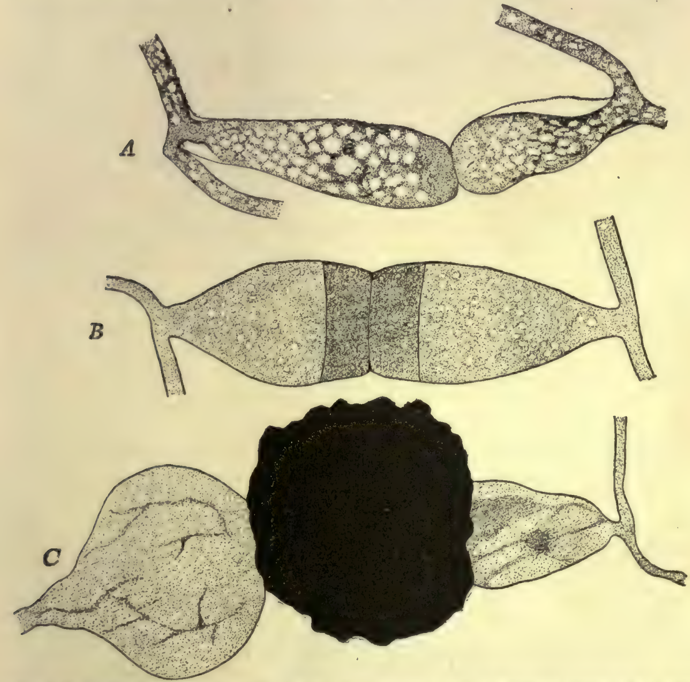

Fig. 130.—Sexual reproduction of *Mucor*, showing tips of sexual branches in contact (*A*), the two gametangia cut off by partition walls (*B*), and the heavy-walled oöspore (*C*); *B* and *C* are more or less diagrammatic as to cell contents.

ing upon a suitable substratum germinate and produce new mycelia. These spores, although asexual, are evidently not swimming spores, as there is no water medium for them to use. This method of transfer being impossible, the spores are scattered by currents of air, and must be correspondingly light and powdery. It is interesting to note that certain molds that grow in the water develop swimming spores.

While the ordinary method of reproduction through the growing season is by means of these rapidly germinating spores, in certain conditions sexual reproduction also occurs. Branches put forth from two contiguous mycelial threads, the tips of the branches being in contact (Fig. 130, *A*). Partition walls separate the tips from the main body of the plant (Fig. 130, *B*), the walls in contact become perforated, the contents of the two tips fuse, and a heavy-walled oöspore is the result (Fig. 130, *C*).* This sexual process suggests that of *Spirogyra* (§ 69).

80. **Peronospora.**—These are the downy mildews, very common parasites on the leaves of seed-plants. The mycelium is entirely internal, branching among the tissues of the leaf, and piercing the living cells with sucker-like branches that rapidly absorb their contents (Fig. 131). The presence of the parasite is made known by discolored and finally deadened spots on the leaves, where the tissues have been killed.

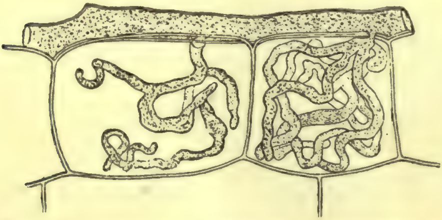

FIG. 131.—Branch of mycelium of *Peronospora* in contact with two cells of a host plant, and sending into them absorbing branches.—After DE BARY.

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* It is not easy to induce *Mucor* to perform the sexual process, and in fact such a process may not often occur in nature.

From this internal mycelium numerous sporophores arise and reach the surface of the leaf; and many of them rising above the surface close together, they form little velvety patches suggesting the name downy mildew. These sporophores, after rising above the surface of the leaf, branch freely and produce spores (Fig. 132). The spores are scattered by the wind, fall upon other leaves, and start new mycelia, which penetrate into the tissues of the leaf and begin their ravages. In this way the parasite spreads with great rapidity, often producing serious epidemics among plants.

In certain conditions special branches arise from the mycelium which bear antheridia and oögonia that remain within the host (Fig. 133). The oögonium develops a single egg. The antheridium comes into contact with it, puts out a tube that pierces the oögonium wall, and discharges its contents (Fig. 133, *B*). As a result of this act

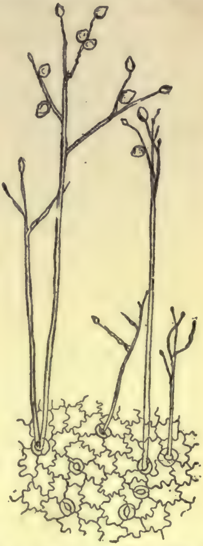

Fig. 132.—Sporophores of a *Peronospora* form rising through the stomata of the host-leaf (potato), branching, and bearing spores; this form causes potato-rot.—After Strasburger.

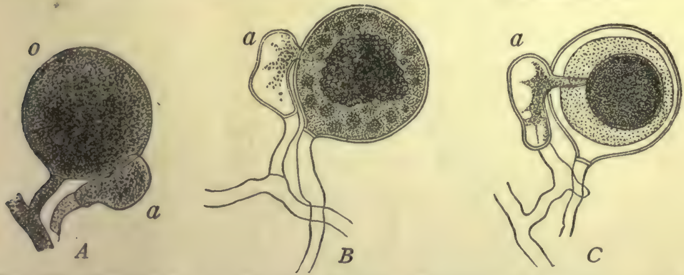

Fig. 133.—*Peronospora: A*, oögonium (*o*) with antheridium (*a*) in contact; *B*, tube from antheridium penetrating oögonium; *C*, oögonium containing oöspore.—After DeBary.

of fertilization, a heavy-walled oöspore is formed within the oögonium (Fig. 133, *C*). The infected leaves containing the oöspores fall and gradually decay, thus liberating the oöspores, which are free to germinate during the next spring and infect new leaves.

The downy mildews include some very destructive parasites, attacking potatoes (potato-rot), grape-vines, lima beans, lettuce, onions, cucumbers, melons, radishes, etc. Various means have been discovered for holding these diseases in check.

81. **Alga-like Fungi.**—*Mucor* and *Peronospora* are representatives of a large group (*Phycomycetes*) of Fungi that most resemble Algæ, and suggest clearly that they are Algæ that have become parasitic or saprophytic. In the whole group the filaments of the mycelium are cœnocytic, as are the bodies of the group of green Algæ to which *Vaucheria* belongs (§ 68). They reproduce by spores, which are usually scattered by the wind, and also produce oöspores. Some of them, represented by *Mucor*, have similar gametes, that are brought together in a way that suggests the *Spirogyra* group among the green Algæ (§ 69); while the others, represented by *Peronospora*, produce eggs and sperms, as in the case of *Vaucheria*, though, since there is no water connection, the sperm reaches the egg through a tube. *Mucor* also illustrates the saprophytes, and *Peronospora* the internal and destructive parasites.

82. **Mildews.**—The true mildews are very common parasites on leaves and other parts of seed-plants, the mycelium spreading over the surface like a cobweb. They are often called powdery mildews in contrast with the downy mildews (§ 80), since in most cases they look like patches of whitish powder on the leaves. A very common form occurs on lilac leaves (Fig. 134), which nearly always show the whitish patches from early summer until fall. Other common mildews attack such valuable plants

as apple, pear, cherry, rose, hop, grape, wheat, gooseberry, cucumber, pea, verbena, sunflower, aster, etc. In fact, very few seed-plants seem to escape their attacks. Being external parasites, mildews are not necessarily destructive; but they often cause the death of the host.

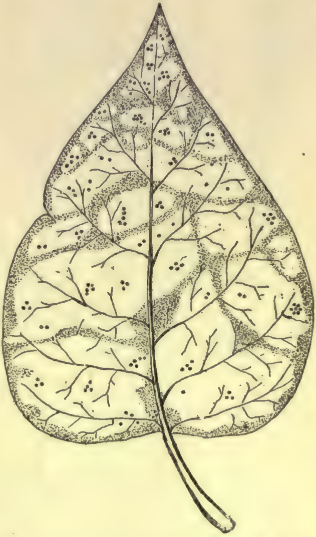
Fig. 134.—Lilac leaf covered with mildew, the shaded regions representing the mycelium, and the black dots the spore-cases.

An examination of the mycelium shows that its filaments have partition walls; and hence the body is not cœnocytic, as in *Mucor* and *Peronospora*, but made up of a row of cells as in the *Conferva* forms among the green Algæ. Small disk-like outgrowths are sent into the epidermal cells of the host, anchoring the mycelium and absorbing the cell contents.

During the summer, numerous sporophores arise from the mycelium, not bearing sporangia, as in *Mucor* (§ 79), but forming spores in a peculiar way. The end of the sporophore rounds off, almost separating itself from the part below, and becomes a spore. Below this another organizes in the same way, then another, until a chain of spores is developed (Fig. 135, *A*), easily broken apart and scattered by the wind. Falling upon other suitable leaves, these spores germinate and produce new mycelia, enabling the parasite to spread with great rapidity.

The mycelium produces also minute antheridia and oögonia, which come in contact with one another as do those of *Peronospora* (§ 80), but it is not worth while for the untrained student to try to observe them. As a result of fertilization, however, a structure called the spore-fruit is developed. These spore-fruits appear on infected leaves as minute dark dots (Fig. 134), each one being a sphere of heavy-walled cells (Fig. 135, *B*), which usually bear hair-like appendages of various forms. In fact, the spore-fruit is a heavy protecting case for spores, and carries mildews through the winter or the dry season. The appearance of a many-celled spore-case as the result of fertilization, rather than a new mycelium, suggests the similar result of fertilization among the red Algæ (§ 75).

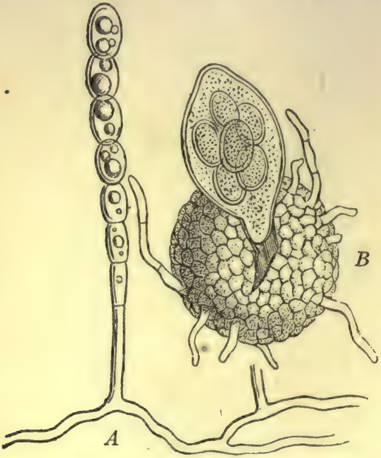

Fig. 135.—Reproduction of mildew: *A*, chain of spores developed by a sporophore; *B*, spore-case burst, and showing the extruded sac (ascus) with its spores.—After Tulasne.

By bursting the wall of this spore-fruit, one or more delicate bladder-like sacs are extruded, and through the transparent wall of each sac several spores may be seen (Fig. 135, *B*). The delicate sacs are called *asci* (singular, *ascus*), a word meaning "sacs," and hence the great group of Fungi represented here by the mildews is named the *Ascomycetes*, which means "sac Fungi." In the life-history of the mildews it is evident that there are two kinds of asexual spores: those produced in chains by the sporophores, and those produced in the sacs of the spore-fruit. Both produce new mycelia, the latter starting the first mycelia of the growing season, and the former multiplying mycelia throughout the growing season.

83. **Other Sac Fungi.**—The group of sac Fungi is a very large one, containing many forms that are well known and

some that are important. All of them, at some period of the life-history, produce spores in sacs, and the sacs are usually contained in a spore-fruit. The spore-fruit is of three general kinds: (1) a hollow sphere, completely enclosing the sacs; (2) a flask-like structure with a small open neck; and (3) a cup-like or saucer-like structure which is lined by a layer of sacs.

The first kind of spore-fruit is illustrated by the mildews just described. It is of interest to know that truffles are such closed spore-fruits, having become large and edible. The truffle Fungi are saprophytic, the mycelium being found especially in forests under decaying leaves. The truffles of commerce are obtained chiefly from France and Italy.

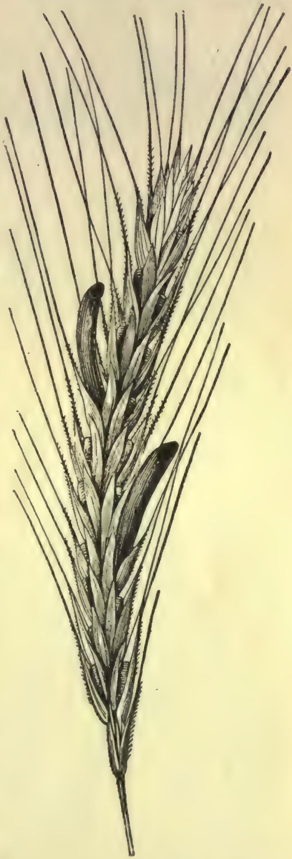

FIG. 136.—Head of rye attacked by ergot fungus, conspicuous growths replacing the grains of rye.—After TULASNE.

The sac Fungi with flask-like spore-fruits are illustrated by many forms growing on dead wood or as parasites under the bark of trees and shrubs, and forming upon the surface of the bark black, wart-like growths that include the spore-fruits, in plum- and cherry-trees producing the disease known as black knot. An important member of this group is the fungus that produces the ergot of medicine. It is parasitic upon the young heads of rye and other grasses, distorting them and producing the excrescent growths from which the ergot is obtained (Fig. 136).

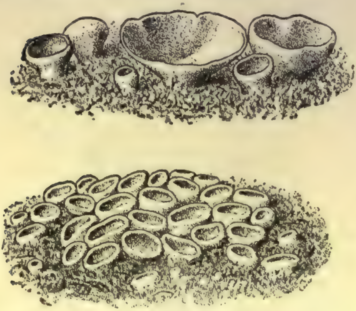

Fig. 137.—Two kinds of cup-fungus. —After Lindau.

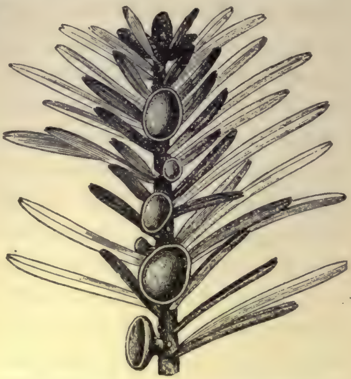

Fig. 138.—A cup-fungus growing on a spruce.—After Rehm.

Most attractive, however, is the group of sac Fungi with spore-fruits shaped like saucers, cups, funnels, flat disks, etc.; for the lining, made up of a layer of the spore-containing sacs, is often some brilliant shade of red, yellow, or brown (Figs. 137 and 138). The scarlet-lined cups of certain forms are often seen on decaying logs, stumps, etc.; and in the morels the spore-fruits get so large and fleshy that they are used as one of the most delicate of the edible mushrooms, although they are not mushrooms at all (Fig. 139).

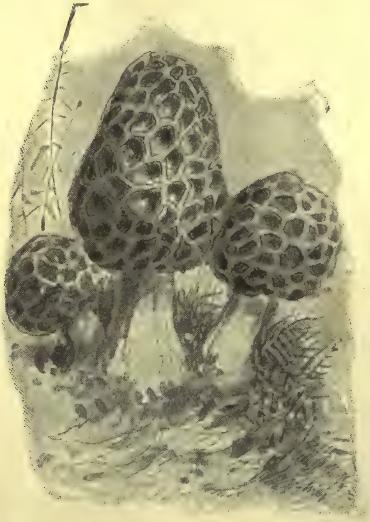

Fig. 139.—The common edible morel, the depressions in the surface being lined by a layer of asci.—After Gibson.

84. **Rusts.**—Rusts are destructive parasites that attack almost all seed-plants, but those that attack the cereals are of special importance. Wheat, oats, rye, and barley all have their rusts; and in the United States there is a yearly loss of several million dollars on account of the ravages of the wheat-rust alone, scarcely a field being entirely free from the pest. Naturally these parasites have been investigated persistently; but while very much has been learned about their life-histories and behavior, no remedy has been discovered. It has been found that certain varieties of wheat resist the rust better than others, and that varieties ripening early escape serious injury; and these facts may lead to the breeding of resistant and early races.

The life-history of a rust is usually very complex, since there are several phases in the history, and all the phases may not occur on the same host plant. Since wheat-rusts are better known than any other, one of them may be used to illustrate the life-history.

While the leaves and the stems of wheat are growing, the mycelium of the parasite is burrowing among the tissues of infected plants. About the time of harvest, numerous sporophores arise from the mycelium and reach the surface of leaves and stems, each sporophore producing at its tip a reddish spore (Fig. 140). These are the *summer spores*, and they occur in such great numbers that they form rusty-looking lines and spots, giving name to the disease. The summer spores are scattered freely by the wind; and those falling upon other plants germinate immediately, the new mycelium penetrating the host plant and beginning its ravages. By

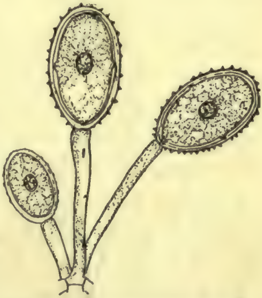

Fig. 140.—The summer spores of wheat-rust.

means of these summer spores the rust may spread through a field of wheat and into adjoining fields with great rapidity.

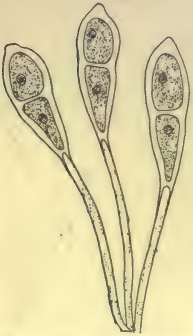

Fig. 141.—The winter spores of wheat-rust.

Later in the season, on the stubble and on plants not removed in the harvesting, black lines and dots appear, which are masses of a very different kind of spore sent to the surface by the mycelium (Fig. 141). This spore, which is two-celled and has a very heavy wall, is the *winter spore;* for it is in this form that the rust usually endures the winter.

In the spring the winter spores, lying where the plants on which they were produced have decayed, begin to germinate, each one of the two cells sending out a short filament. This filament is not a parasite, but a saprophyte, and usually consists of four cells, each one of which sends out a little branch, at the tip of which a small spore is produced (Fig. 142). These may be called *early spring spores.*

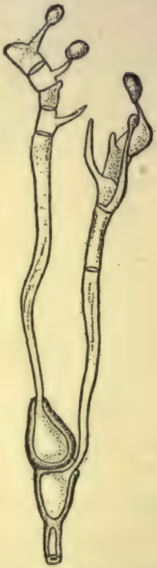

Fig. 142. — A winter spore of wheat-rust germinating, each filament producing four cells, each of which sends out a branch that produces at its tip a spore (early spring spore). — After Tulasne.

These early spring spores are scattered by the wind; and those falling upon barberry leaves germinate, the new mycelia entering and spreading through the leaves. In this phase the rust is parasitic upon an entirely different host, and one that holds no relation to wheat. The mycelium in the barberry leaves sends to the leaf surface, usually the under one, groups of sporophores, each group surrounded by a cup-like structure; and hence these cup-like clusters have been called *cluster-cups*. In these cluster-cups the spores occur in long chains, and may be called *spring spores* or *cluster-cup spores* (Fig. 143).

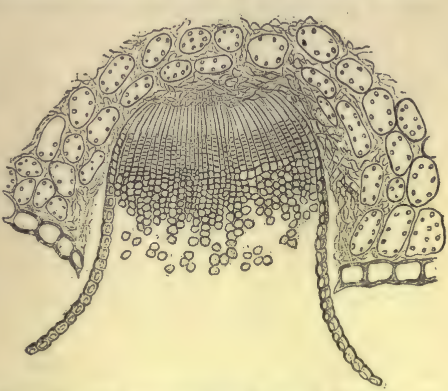

Fig. 143.—A cluster-cup (on barberry) of wheat-rust containing chains of spring spores.—After Strasburger.

These spring spores on the barberry leaves are scattered by the wind and infect young wheat plants; that is, germinate and produce mycelia which penetrate them. These new mycelia later put forth the summer spores, and in this way the life cycle has returned to the point with which this account began.

It will be noted that in this life-history there are four kinds of spores: (1) the early spring spores, produced by a simple saprophytic filament, and infecting barberry leaves; (2) the spring or cluster-cup spores, produced by a mycelium parasitic on the barberry, and infecting young wheat plants; (3) the summer spores, produced by a mycelium parasitic on wheat, and infecting other wheat plants; (4) the winter spores, produced by the same mycelium, and in spring producing the saprophytic filaments. In the United States the barberry is not widely distributed enough to play so important a part in the life-history of wheat-rust, and other seed-plants have been found to be used as hosts for the cluster-cup stage of certain forms of rust. It is also stated that the cluster-cup stage may be omitted, in that case the early spring spores infecting wheat plants rather than barberry leaves; and recently it has been shown that often the summer spores survive the severest winter and infect young wheat plants of the next season.

Another well-known rust is that which attacks apple-trees and their relatives, the wild crab, hawthorn, etc. The stage on the apple-tree is the cluster-cup stage, the cluster-cups occurring on the under surface of the leaves; the mycelium also attacks and ruins the fruit, the cluster-cups being seen in connection with the diseased parts. The cluster-cup spores infect the cedars, producing swellings half an inch or more in diameter and known as cedar-apples (Fig. 144). In the spring these cedar-apples become conspicuous, especially after a rain, when the jelly-like masses containing the orange-colored spores swell. These spores are blown about and infect the apples. Attempts are made to check the apple-rust by destroying the cedar-trees and by spraying the apple-trees, when they are putting out their leaves, with a liquid that kills such Fungi.

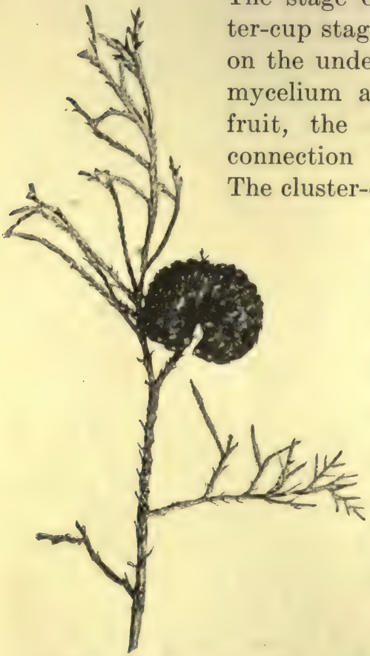

FIG. 144.—A cedar-apple.

Although rusts possess several kinds of ordinary (asexual) spores, no oöspores (sexually formed spores) have been observed; but a process in the life-history representing a sexual act has been discovered in some forms.

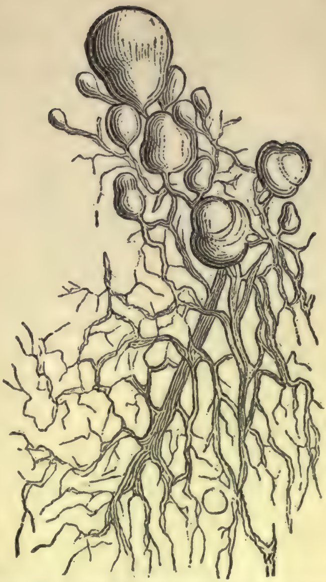

Fig. 145.—Mycelium of a mushroom producing sporophores (buttons).—After Sachs.

85. **Mushrooms.** — This name is a very indefinite one; sometimes applying to any of the fleshy Fungi of the umbrella form, and sometimes including among such forms only those that are edible, the poisonous ones being spoken of as toadstools. For our purpose, no exact definition of the word is necessary, it being used as the common name of a group of forms with which the student should be somewhat familiar.

The life-history of the ordinary edible mushroom

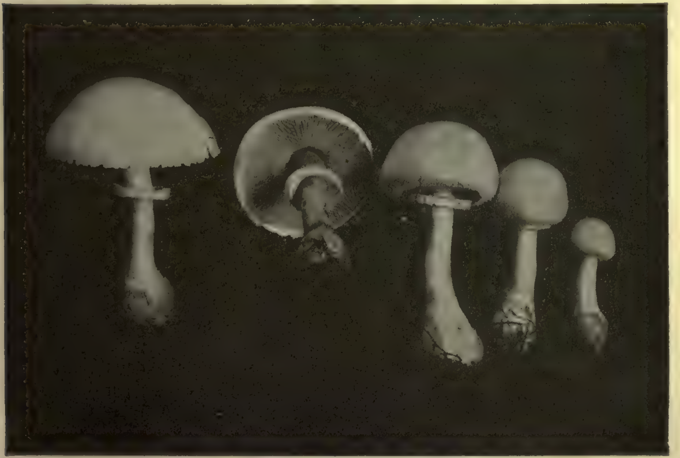

Fig. 146.—A common edible mushroom (*Lepiota*).

of the markets will serve as an illustration. The mycelium of white branching threads spreads extensively through the substratum of decaying organic material, and by those who grow mushrooms is called spawn. This mycelium, although the least conspicuous part of the mushroom, is, of course, the real vegetative body. Upon this underground mycelium little knob-like protuberances arise (buttons), growing larger and larger (Fig. 145) until they develop into the umbrella-like structures commonly spoken of as mushrooms (Fig. 146). This umbrella-like structure, however, corresponds to the sporophores that arise from the mycelia of other groups of Fungi, except that it includes a large number of sporophores organized into a single large body. Therefore, the real mushroom body is a subterranean mycelium, upon which the struc-

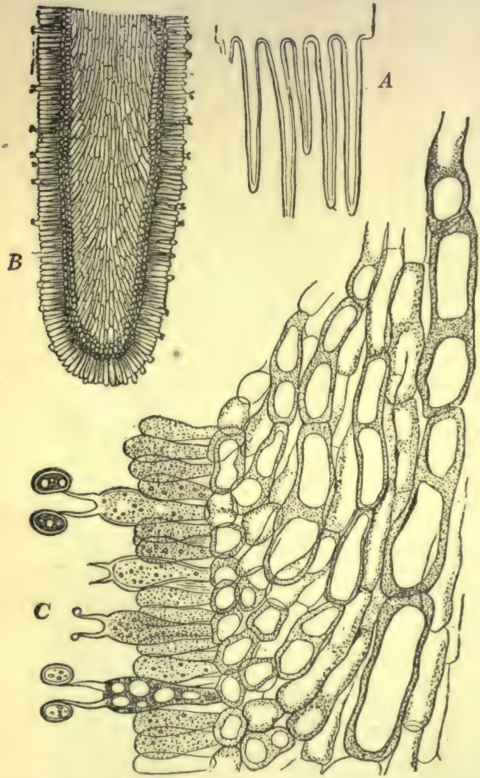

FIG. 147.—Sections through the gills of a common mushroom: *A*, gills hanging from the pileus; *B*, single gill showing the basidium layer; *C*, much enlarged view, showing the basidia-bearing spores. —After SACHS.

tures commonly called mushrooms are the spore-bearing branches. In pulling up a mushroom, fragments of the mycelium may often be seen attached to it, looking like small rootlets. In the following description, however, the word mushroom will be used in its ordinary sense.

The mushroom has a stalk-like portion (*stipe*) and an expanded umbrella-like top (*pileus*). On the under side of the pileus there are found thin, radiating, knife-blade-like plates (*gills*) (Fig. 147, *A*). The surface of the gills consists of a layer of peculiar club-shaped cells called *basidia* (Fig. 147, *B*). From the broad end of each basidium usually four delicate branches arise, each producing at its tip a minute spore (Fig. 147, *C*). The ripe spores shower down from the gill surfaces, germinate, and produce new mycelia.

The most common edible mushrooms grow in fields and pastures; but there are numerous mushrooms in the deep woods, in fact wherever there is decaying organic material. It has been found impossible to give directions for distinguishing edible and poisonous forms that can be used by those who are not familiar with mushrooms. It is exceedingly unsafe for an inexperienced person to gather wild mushrooms for eating, for some of the deadliest forms resemble in a general way those commonly eaten.

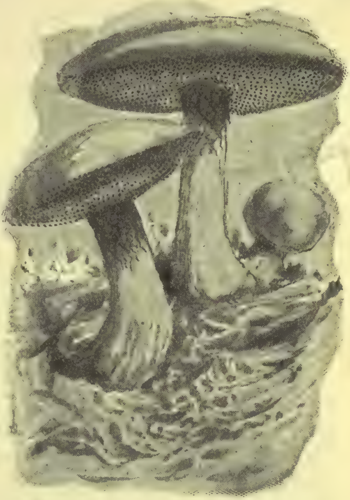

FIG. 148.—A common pore-fungus.—After GIBSON.

The mushrooms with gills form a very large group, but numerous forms display the spore-producing layer in other ways. For example, the pore Fungi are so named because they have pore-like depressions or tubes lined by the basidium-layer, instead of gills. In addition to umbrella-like forms among the pore Fungi (Fig. 148), there are the numerous bracket Fungi, which appear as hard hoof-like outgrowths on tree trunks (Fig. 149), stumps, etc. Some of these bracket Fungi are perennial, showing annual layers of growth, as the common touchwood or punk. Other mushrooms have the umbrella-like bodies, but instead of either gills or pores, there are spine-like processes coated by the spore-forming layer (Fig. 150); others appear as

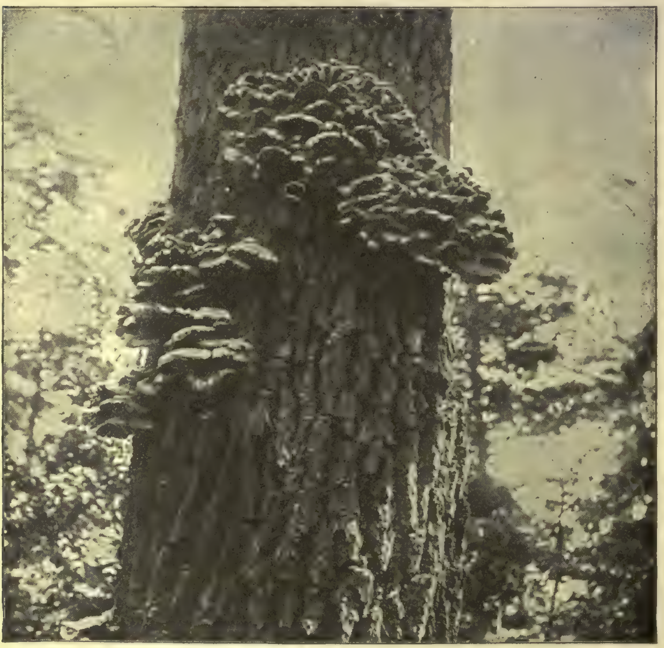

Fig. 149.—A bracket-fungus (pore-fungus) growing on red oak.

gelatinous, dark-brown, shell-shaped masses, resembling ears; still others resemble fleshy branching corals (Fig. 151), and hence are called coral Fungi.

In general, mushrooms are harmless and often useful saprophytes, but there are also destructive parasitic forms that attack forest-trees. The mycelium usually spreads between the bark and the wood, sending special absorbing branches into the wood, often even into the heart wood, causing decay and weakening of the stem. The spore-bearing structures are sent to the surface, and appear as toadstools, bracket Fungi, etc. Spores are produced in great profusion and infect other trees, the new mycelium using wounds to effect its entrance. Some mycelia spread through the soil, inoculating trees through their roots; while

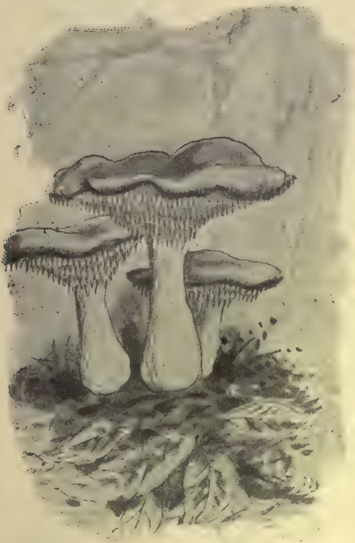

Fig. 150.—Mushroom with spine-like processes instead of gills.—After Gibson.

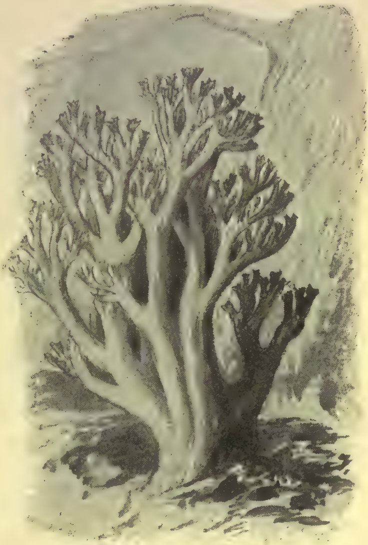

Fig. 151.—The common edible coral fungus.—After Gibson.

in other cases the spores are scattered by the wind and the infection starts in the tree tops. Almost all full-grown trees are diseased at some point.

86. **Puffballs.**—The puffballs are fleshy Fungi that differ from the mushrooms in having the spores enclosed until they are ripe (Fig. 152). There is a subterranean mycelium, as in the mushrooms; but the spore-bearing structure is a fleshy, globular body, containing irregular chambers lined with the spore-producing layer. When young, this body is solid and white; but as the spores mature, it becomes yellowish and brownish, gradually dries up, and finally is only a brown parchment-like shell containing innumerable, exceedingly small spores that are discharged by the breaking of the shell. Some of the puffballs become very large, reaching a diameter of twelve to eighteen inches.

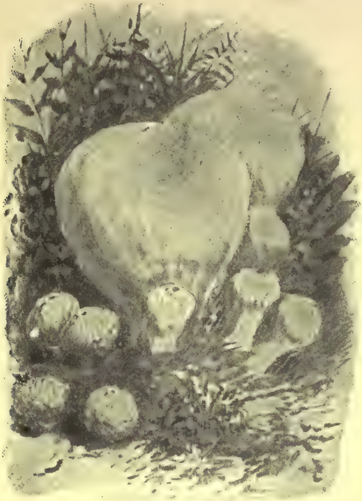

Fig. 152.—Puffballs.—After Gibson.

87. **The highest group of Fungi.**—The rusts, mushrooms, and puffballs represent the highest and most extensive group of Fungi, characterized by producing spores by means of a basidium, and hence called *Basidiomycetes*, which means "basidium Fungi." The peculiarity of the basidium is that it sends out branches, each of which produces a spore at its tip (Fig. 147, *C*). The layers of basidia (spore-producing cells) were noted in the mushrooms and the puff-

balls; but it is thought that a basidium is represented also in the life-history of the rusts, and hence they are now included among the Basidiomycetes. This supposed basidium of the rust is the little filament produced by the winter spore, which sends out branches that bear the small early spring spores (§ 84).

88. **Mycorhiza.**—This name means root-fungus, and refers to an association that exists between certain Fungi of the soil and the roots of higher plants. It was thought once that this association of fungus and root occurred only in connection with a limited number of higher plants, such as orchids, oaks, heath plants, etc.; but more recent study indicates that probably the large majority of vascular plants, that is, plants with true roots, have developed this relation to a soil fungus, the water-plants being excepted. It has been found that the humus soil of forests is in large part "a living mass of innumerable filamentous Fungi." It is of advantage to roots to relate themselves to this great network of filaments, which are already in the best relations for absorption; and those plants which are unable to do this are at a disadvantage in the competition for the nutrient materials of the forest soil. It is doubtful whether many vascular green plants can absorb from the soil enough for their needs without this assistance; and if this is true, the mycorhiza Fungi become of vital importance in the nutrition of such plants. The delicate branching filaments of the mycelium either enwrap the rootlets with a jacket of interwoven threads (Fig. 153), or occur within the cortical cells of the root.

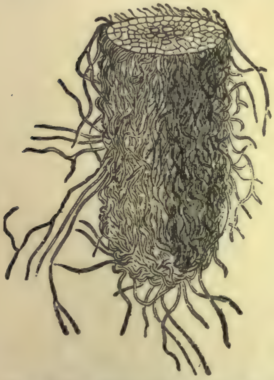
FIG. 153.—Mycorhiza: the tip of a beech rootlet enmeshed by a soil fungus.—After FRANK.

89. **Lichens.**—Lichens are abundant everywhere, forming splotches of various colors on tree trunks, rocks, old boards, etc., and growing also upon the ground (Figs. 154 and 155). They have a general greenish-gray color, but brighter colors also may be observed.

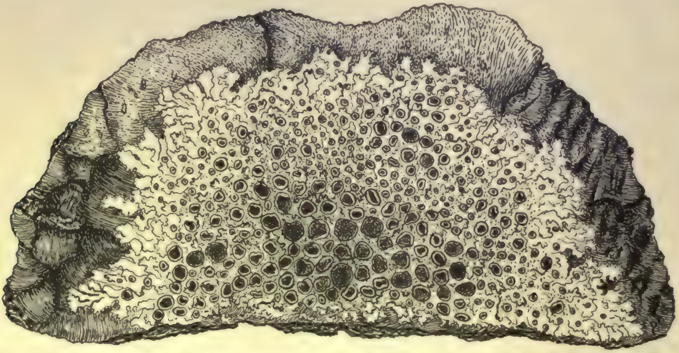

FIG. 154.—A common lichen growing on bark; the numerous dark disks are lined by a layer of asci.

The great interest connected with lichens is that they

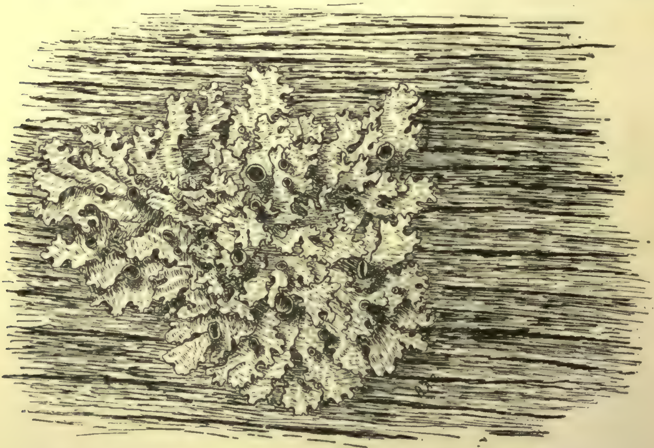

FIG. 155.—A common foliose lichen growing upon a board.

are not single plants, but that each lichen is formed of a fungus and an alga living together so intimately as to appear like a single plant. In other words, a lichen is not an individual but a firm of two individuals, very unlike one another. If a lichen be sectioned, the relation between the two constituent plants may be seen (Fig. 156). The fungus makes the bulk of the body with its interwoven mycelial threads, in the meshes of which lie the Algæ, sometimes scattered, sometimes massed. It is these enmeshed Algæ, showing through the transparent mycelium, that give the greenish tint to the lichen.

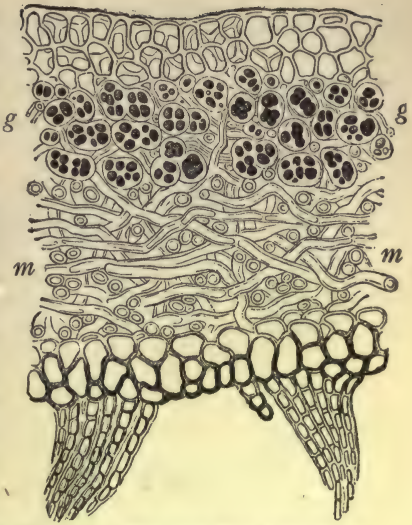

FIG. 156.—Cross-section of a lichen, showing the interwoven mycelium of the fungus (m) and the enmeshed alga (g).—After SACHS.

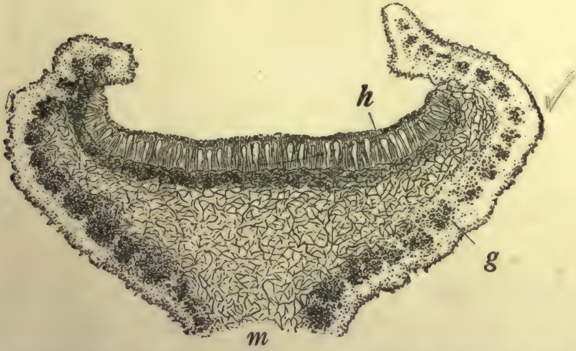

FIG. 157.—Section of one of the cup-like bodies of a lichen, showing the stalk of the cup (m), the masses of Algæ (g), and the lining layer of asci (h).—After SACHS.

It has been found that the lichen-alga can live quite independently of the lichen-fungus. In fact, the enmeshed Algæ are often recognized as identical with forms living independently, the forms usually being certain blue-green

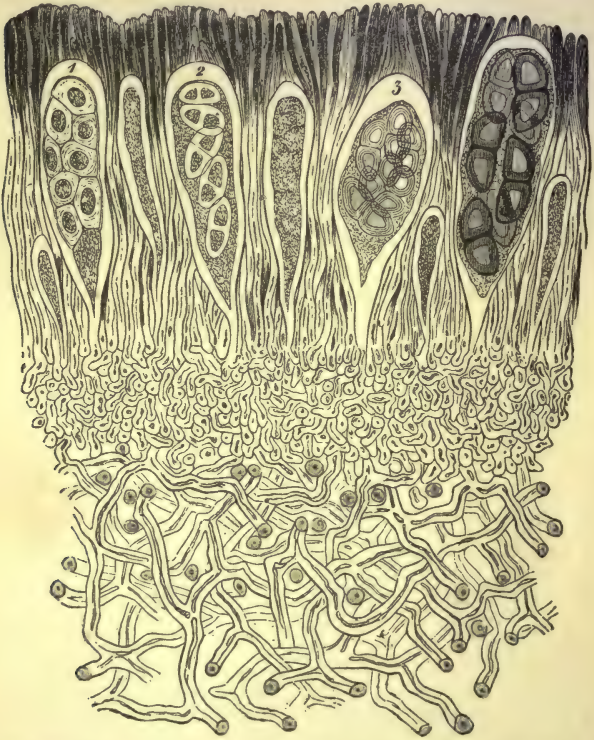

Fig. 158.—Much enlarged section of portion of lining layer, showing the asci (1, 2, 3, 4) with their contained spores.—After Sachs.

Algæ and some of the simpler green Algæ. On the other hand, it has been found that the lichen-fungus is completely dependent upon the Algæ; for the germinating spores of the fungus do not develop far unless the young mycelium can lay hold of suitable Algæ. Artificial lichens also have been made by bringing together wild Algæ and lichen-fungi. Lichens, therefore, are really combinations of a parasitic fungus and its host, the parasitism being peculiar in that the host is not injured. The fungus lives upon the food made by the alga, and the relation suggested is that the alga is enslaved by the fungus.

At certain times cup-like or disk-like bodies appear upon the surface of the lichen, with brown or black or more brightly colored lining (Fig. 154). A section through these bodies shows that the colored lining is largely made up of delicate sacs containing spores (Figs. 157 and 158). It is evident, therefore, that such a lichen-fungus is one of the Ascomycetes (§ 82), and it is this group of Fungi that

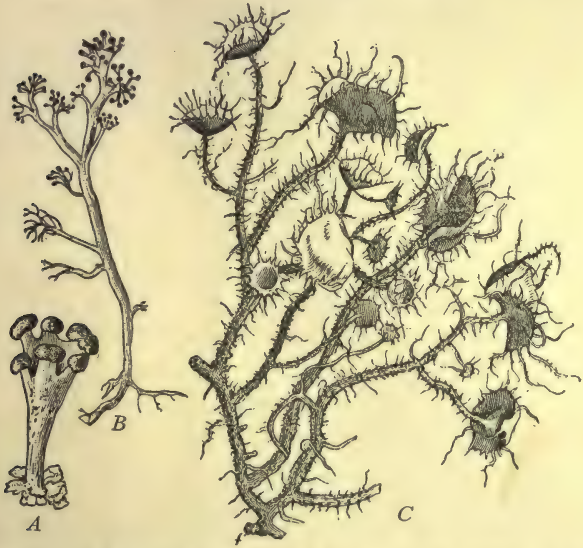

Fig. 159.—Fruticose lichens: *A*, a simple form; *B*, reindeer moss; *C*, a common hanging lichen.—*A* and *B* after Strasburger; *C*, after Sachs.

is chiefly concerned in forming lichens. Some Basidiomycetes also have learned to form lichens.

Various forms of lichens can be distinguished as follows: (1) *crustaceous lichens,* in which the body resembles an incrustation upon its substratum of rock, soil, etc.; (2) *foliose lichens,* with flattened, leaf-like, lobed bodies, attached only at the middle or irregularly to the substratum (Fig. 155); (3) *fruticose lichens,* with slender bodies branching like shrubs, either erect, hanging, or prostrate (Fig. 159).

Lichens are often very important in starting a humus formation on bare rocks and sterile soil. In such exposed situations Algæ could not endure alone, and of course Fungi could not exist alone in any situation. The lichen combination can exist, however, since the fungus obtains its food from the Algæ, while the latter are protected against drying out by the enveloping meshwork of the fungus. As the lichens grow and decay, enough humus is collected for higher forms of plant life to start; and these in turn contribute to a more rapid accumulation of humus, until presently a respectable soil may be the result.

CHAPTER VIII

LIVERWORTS

90. Summary.—As an introduction to liverworts it is well to state the most important facts in reference to the Algæ and Fungi. The Algæ and Fungi together constitute the first great division of the plant kingdom, known as *Thallophytes.* The name means "thallus plants," and "thallus" means a body usually prostrate and having no special vegetative organs as leaves and roots. Such a definition cannot be very rigid, for some Algæ cannot be said to have strictly thallus bodies, and in the higher groups thallus bodies also occur; but the name is a convenient one to apply to all plants below the liverworts.

As the study of the higher plants is begun, the important progress made by the Thallophytes must be kept clearly in mind, for the liverworts start with this progress behind them. The important progress may be stated as follows:

(1) *Increasing complexity of the plant body.*—Beginning with single isolated cells, the plant body reaches considerable complexity among the Thallophytes, in the form of simple or branching filaments, plates of cells, and masses of cells.

(2) *Appearance of spores.*—Beginning with reproduction by vegetative multiplication, the Thallophytes soon develop special cells for reproduction (spores), and produce them not only in abundance but in a variety of methods and forms.

(3) *Appearance of sexual cells.*—After ordinary spores appear, the Thallophytes also introduce a third form of

reproduction by producing sexual cells (gametes), which by fusing in pairs (fertilization) form oöspores. At first the pairing gametes are alike, but later they become very different, and are called sperms and eggs. The organ producing sperms is called the antheridium, and that producing an egg the oögonium; and among the Thallophytes each of these organs consists of a single cell.

(4) *Algæ the independent line.*—This means not only that the Fungi have probably been derived from the Algæ by losing the ability to make their own food, but also that the higher plants have been derived from the Algæ. Accordingly the liverworts, about to be studied, are believed to have developed from the Algæ.

91. **General character of Liverworts.**—Liverworts are found in a variety of conditions, some floating, many in damp places, and many on the bark of trees. They seem to be plants that have barely learned to live on land, and this change from the water to the land is one of the greatest and most important in the history of plants. Although in general they are moisture-loving, some can endure great dryness, so that the land habit can be said to have become well-established among the liverworts.

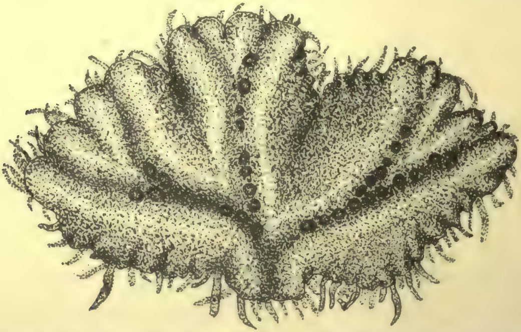

FIG. 160.—*Ricciocarpus:* showing thallose body, forked branching, rhizoids on the under surface, and spore-cases along the main axes (showing position of archegonia).

The plant body is flat and compact, lying prostrate upon its substratum, and is often a thallus; that is, it shows no distinction of stem and leaves, the whole body appearing leaf-like (Fig. 160). The upper surface of the body is freely exposed to the light, but the lower surface is against the substratum and puts out hair-like processes (*rhizoids*) for anchorage. If the body is thin, all the cells contain chloroplasts; but if the body is so thick that the light cannot penetrate it, the under layers of cells are not green.

92. **Marchantia.**—*Marchantia* is one of the most common and conspicuous liverworts. The body is a thick thallus that forks repeatedly, giving the appearance of notches of greater or less depth (general habit as in Fig. 160). The central axis of the thallus, or of a branch, ends in the terminal notch, in the bottom of which, therefore, is the growing tip. The upper surface of the *Marchantia* body is blocked off into small rhombic areas, in the center of each one of which is a minute opening (Fig. 162).

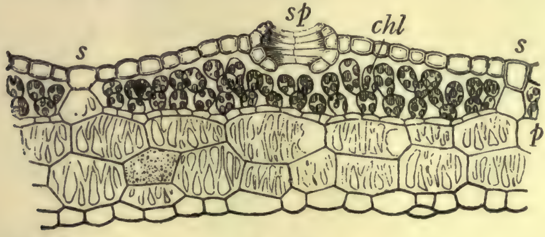

FIG. 161.—*Marchantia*, cross-section of thallus: showing lower epidermis (from which, in other parts of the thallus, rhizoids are developed), two layers of colorless cells (*p*), and one large air-chamber (*s*, *s*, the bounding walls) containing cells with chloroplasts (*chl*) and pierced by a chimney-like air-pore (*sp*).—After GOEBEL.

A section through this body shows its general structure (Fig. 161). Beginning with the lower side, there is seen first the layer of cells forming the epidermis, from which the rhizoids and certain other appendages arise; above this epidermis there are several layers of colorless cells; above these there is a series of large air-chambers into which project the curious cells containing the chloroplasts; and forming the dome-like roof of each air-chamber is the upper epidermis, pierced by a single air-pore in the center of the roof of each chamber. Each air-pore resembles a little chimney, built up with several tiers of cells. The rhombic areas seen on the surface of the body are the outlines of the air-chambers, and the minute opening in the center of each is the air-pore (Fig. 162). This arrangement of cells containing chloroplasts exposed in air-chambers that communicate freely through air-pores suggests the same general mechanism for plant work as that described for leaves, with their internal atmosphere and stomata (§13).

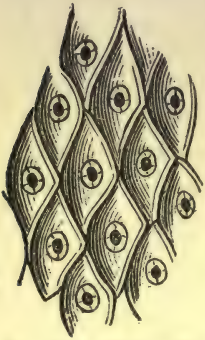

Fig. 162. — *Marchantia:* rhombic areas on upper surface of thallus (surface outline of air-chambers), each one pierced by an air-pore.—After Sachs.

A remarkable fact connected with the *Marchantia* body, as contrasted with that of the Thallophytes, is that it produces no spores. However, provision for rapid multiplication is made by the production of peculiar reproductive bodies that are developed in little cups on

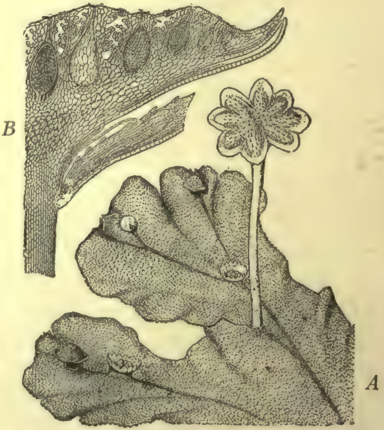

Fig. 163.—*Marchantia: A*, thallus bearing little cups containing reproductive bodies, and an antheridial branch with its disk, as well as some very young antheridial branches; *B*, section through antheridial disk, showing the sunken antheridia.—After Kny.

the back of the thallus (Fig. 163). These bodies are round and flat (biscuit-shaped) and many-celled, and falling out of the cup they start new thallus bodies.

Although the thallus body produces no spores, it does produce sex-organs. In *Marchantia*, long, erect, stem-like branches arise from the thallus, bearing at their summits conspicuous disks that contain the sex-organs. The disks containing antheridia are lobed or scalloped (Fig. 163); while those containing the egg-producing organs are star-shaped (Fig. 165). The two kinds of disks are not found on the same plant.

93. The antheridium. — The sperm-producing organ is called an *antheridium*, but it is very different from the antheridia of the Thallophytes. Instead of being a single cell, it is a stalked, club-shaped or globular, many-celled structure (Fig. 164). A single layer of cells forms the covering, and within it there is a closely packed mass of small cells, each one of which produces a sperm. The sperm is a very small cell with two long cilia, and these small biciliate sperms are one of the distinguishing features of the liverworts and their allies.

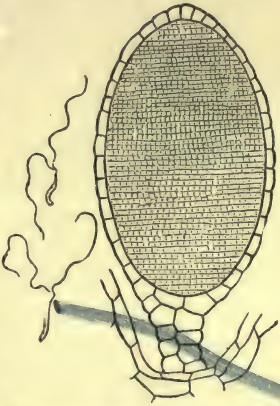
FIG. 164.—*Marchantia:* antheridium and two sperms. — After SACHS.

94. The archegonium.—The egg-producing organ is called the *archegonium*, and it is very different from the oögonium of the Thallophytes. Instead of being a single cell, it is a many-celled structure, shaped like a flask with a long neck, and within the bulbous base the single egg is formed (Fig. 165, *B*, and Fig. 166). To this neck the swimming sperms are attracted; they enter and pass down it, one of them fuses with the egg, and an oöspore is formed. It is evident that fertilization can take place only in the presence of moisture.

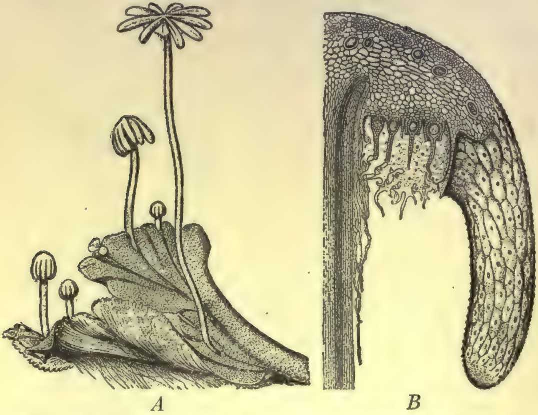

FIG. 165.—*Marchantia:* A, thallus bearing archegonial branches of various ages; *B*, section through portion of archegonial disk, showing pendant archegonia.—After KNY.

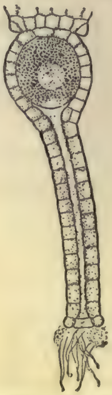

FIG. 166.—*Marchantia:* archegonium, containing an egg; sperms seen at the mouth of the neck. —After KNY.

95. **The spore-case.**—As soon as the oöspore is formed it begins to germinate; but instead of forming a new *Marchantia* thallus, it produces a very different structure. The oöspore germinates just where it was formed, that is, in the bulbous base of the archegonium; and there the new structure grows. When it is fully developed it is seen to consist of a terminal spore-case full of spores, and a sterile base (Fig. 167, *A*). While growing, this spore-case becomes anchored in the *Marchantia* body (that is, in the archegonium-bearing disk) by the sterile base,

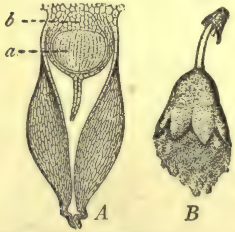

FIG. 167.—*Marchantia: A*, sporophyte formed within the enlarged archegonium, showing the spore-bearing (*a*) and sterile (*b*) regions; *B*, spore-case discharging spores, the sterile region of the sporophyte having developed into a stalk.—After KNY.

and absorbs the necessary nourishment from it. When ripe, the spore-case is ruptured (Fig. 167, *B*), and the light spores are scattered; and when they germinate they produce new thallus bodies.

96. **Alternation of generations.**—The life-history of *Marchantia* shows a distinct alternation of generations, and since this is a feature of all the higher plants it is necessary to understand it clearly. The thallus body produces no spores, but produces sperms and eggs; that is, it produces gametes, and hence is called a *gametophyte*, which means a "gamete plant." The gametes produce an oöspore; but the oöspore does not produce a new thallus plant, producing instead a spore-case. This structure, called the spore-case, does not produce gametes, but produces spores; and hence it is called a *sporophyte*, which means a "spore plant." Thus in the life-history of *Marchantia* and of all higher plants, there is an alternation of gametophyte and sporophyte. It is evident that in this alternation of generations the gametophyte is the sexual and the sporophyte is the sexless generation. Therefore, oöspores are produced by the gametophyte, and ordinary spores by the sporophyte; but the oöspores always produce sporophytes, and the ordinary spores always produce gametophytes. These relations may be indicated clearly by the following formula, in which *G* and *S* are used for gametophyte and sporophyte respectively:

$$G\left\{\begin{matrix}-\mathrm{o}\diagdown\\-\mathrm{o}\diagup\end{matrix}\right.\mathrm{o}-S-\mathrm{o}-G\left\{\begin{matrix}-\mathrm{o}\diagdown\\-\mathrm{o}\diagup\end{matrix}\right.\mathrm{o}-S-\mathrm{o}-G,\text{ etc.}$$

The formula indicates that the gametophyte produces two gametes, which fuse to form an oöspore, which produces the sporophyte, which produces an ordinary spore, which produces a gametophyte, etc. It will be remembered that a similar alternation of generations was noted in the red Algæ (§ 75) and in the mildews (§ 82) among the Thallophytes, but it is not definite and universal until the liverworts are reached.

It is important to note that in this life-history the protected stage of the plant, that is, the stage which can endure the winter, is not a heavy-walled oöspore, as is common among the Thallophytes, but the spore-case or sporophyte.

97. **Other Marchantia forms.**—Associated with *Marchantia* are other liverworts that are much simpler, and which are really better to study if they are available. They differ in having thallus bodies thinner, and hence simpler, in structure; in having the sex-organs directly upon the thallus or embedded in it; and in having simpler and more easily observed spore-cases or sporophytes.*

98. **Jungermannia forms.**—These are commonly called the leafy liverworts, and they are by far the largest group of liverworts. They grow in damp places; or in drier situations on rocks, ground, logs, or tree trunks; or in the tropics on the leaves of forest plants. They are generally delicate plants, and resemble small mosses, many of them being commonly mistaken for mosses.

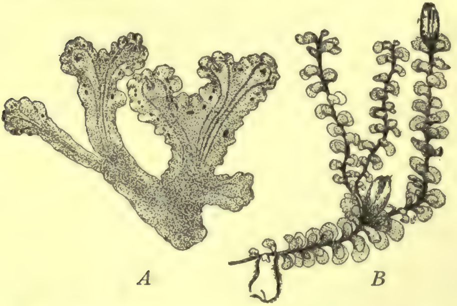

FIG. 168.—*Jungermannia* forms: *A*, thallose form; *B*, leafy form.

The common name of the group suggests one of its principal features. The lowest forms have a very simple thallus body (Fig. 168, *A*); but in most of the forms the body consists of a central stem-like axis bearing two rows of small, often crowded leaves (Fig. 168, *B*). There are really three rows of leaves, but the third is against the substratum and is usually so much changed in appearance as not to resemble the other rows.

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* In case either *Ricciocarpus* or *Riccia* can be obtained, it should be studied rather than *Marchantia*.

There is, of course, the same alternation of generations as in the *Marchantia* forms, but the sporophyte is more than a spore-case. It develops a distinct stalk or stem that bears a spore-case at its summit, and therefore the sporophyte has become more complex. Besides, the spore-case does not burst open somewhat irregularly, as in the *Marchantia* forms, but splits into four pieces that spread apart and expose the spores.

99. **Anthoceros forms.**—This group contains comparatively few forms; but they are of great interest, since many suppose that they are the liverworts that approach most nearly the higher plants. The thallus body is very simple, not becoming so thick as are the *Marchantia* bodies, nor becoming leafy bodies as are those of the leafy liverworts.

The important feature of the group is the sporophyte. At the "fruiting" period the thallus becomes more or less covered by structures that look like small, erect grass-blades (Fig. 169). Each of these blade-like bodies is a sporophyte that has developed from an oöspore lying within an archegonium. The sporophyte has a large bulbous base embedded in the simple thallus, and above this base there arises a long pod-like spore-case. The cells forming the wall of this spore-case contain chloroplasts, so that the sporophyte is able to make food for itself,

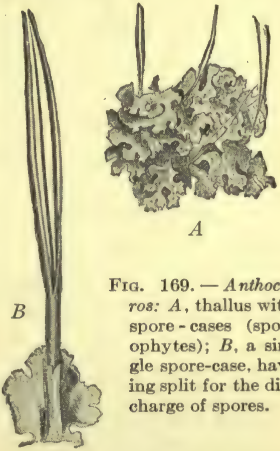


FIG. 169. — *Anthoceros: A*, thallus with spore-cases (sporophytes); *B*, a single spore-case, having split for the discharge of spores.

in addition to absorbing food from the thallus through the bulbous base. In the other liverworts the sporophyte is entirely dependent upon the gametophyte for its food; but in the *Anthoceros* forms the sporophyte, by developing green tissue, has begun to be somewhat independent.

Another important feature of the sporophyte of this group is that it continues to increase in length like a stem, but the growth takes place at the bottom of the spore-case. As the pod-like spore-case splits into two valves, beginning at the top, the ripe spores above are first exposed and scattered; as the splitting becomes deeper the region of the younger spores is reached; and so on until the capsule has become completely split, and all the spores have been exposed (Fig. 169, *B*).

It is evident that the *Anthoceros* forms have the most complex sporophytes among liverworts. In addition to producing spores, these sporophytes have a bulbous absorbing base and develop green tissue for the manufacture of food.

CHAPTER IX

MOSSES

100. General character.—Mosses are very abundant and familiar plants that occur almost everywhere. They grow in all conditions of moisture, from submerged to very dry. Many of them can endure drying out wonderfully; and hence they can grow in very much exposed situations, as do many lichens. In fact, lichens and mosses, being able to grow in the most exposed situations, are the first plants to appear upon bare rocks and ground, and are the last plants one sees in climbing high mountains or in going into very high latitudes.

Mosses have great power of vegetative multiplication, new leafy branches putting out from old ones indefinitely, thus forming thick carpets and masses. Bog mosses often completely fill up bogs or small ponds and lakes with a dense growth, which dies below and continues to grow above so long as the conditions are favorable. These quaking bogs or "mosses," as they are sometimes called, furnish very treacherous footing unless rendered firmer by other plants.

101. Peat.—In moss-filled bogs the water and the dense vegetation shut off the lower strata of moss from complete decay; and they become modified into a coaly substance called *peat*, which may accumulate to considerable thickness by the continued upward growth of the mass of moss. Other marsh plants are associated with mosses in the formation of peat, and often the preservation of these plants is remarkable. In fact, the water of peat-bogs is antiseptic, and in such bogs there are often found almost perfectly preserved specimens of ancient trees or their parts and sometimes of mired animals.

Peat is extensively used for fuel, being cut into bricks and allowed to dry. The less decomposed peat is brown, and the more completely decomposed is nearly black. It is not formed to any large extent in warm countries, probably on account of the rapid decay of vegetation; but in the cooler parts of the globe it has been formed in very large masses. All through northern Asia and Europe, and in the northern United States and Canada, there are millions of acres of peat; but little use has been made of it yet in the United States. Its extensive use in Ireland is well known, but there it is more apt to be called turf than peat.

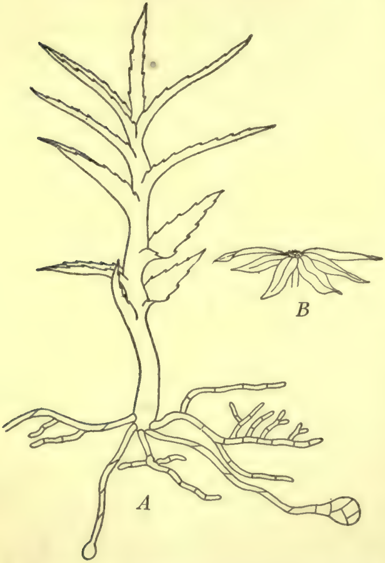


Fig. 170.—An ordinary moss plant, showing the leafy stem (*A*) with its rhizoids, and a rosette (*B*) containing sex-organs.

102. **Life-history of a Moss.**—The conspicuous part of an ordinary moss plant consists of a more or less erect and usually branching stem bearing numerous delicate leaves (Fig. 170, *A*). This plant is evidently able to make its own food, and it is anchored to its substratum by hair-like rhizoids. Its power of vegetative propagation has been described, but it produces no spores. At certain times, however, there usually appears at the end of the main stem or at the end of a branch a rosette of

leaves (Fig. 170, *B*), often called the moss flower. In the center of this rosette there is a group of antheridia and archegonia, sometimes both kinds of organs in a single rosette, sometimes only one kind.

The antheridia are club-shaped organs containing numerous biciliate sperms (Fig. 171, *A*); and the archegonia are flask-shaped organs usually with very long necks, and containing a single egg in the bulbous base (Fig. 171, *B* and *C*). These sex-organs are exactly like those described for liverworts (§§ 93 and 94). It is evident that this leafy

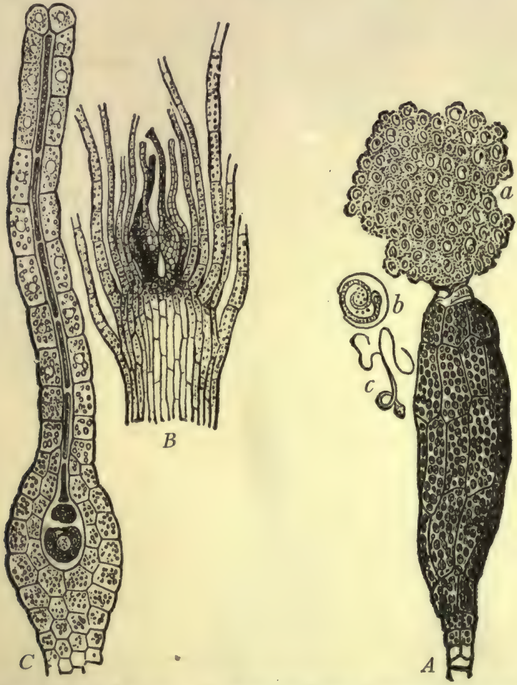


Fig. 171.—Sex-organs of a moss: *A*, an antheridium discharging a mass of mother-cells (*a*) containing sperms, and also a single enlarged mother-cell (*b*) and sperm (*c*); *B*, a group of archegonia within a rosette of leaves; *C*, an archegonium.—After Sachs.

moss plant, which does not produce spores, but which does produce sex-organs, is the gametophyte generation in the life-history. It is plain that the ciliated sperms are organized for swimming, and that fertilization can take place only when there is sufficient moisture for this purpose.

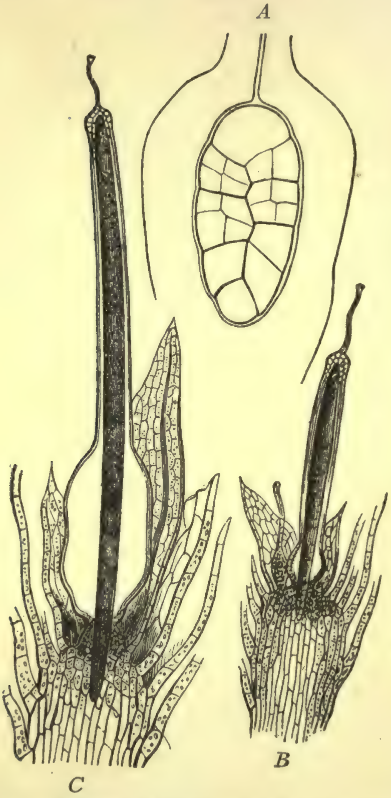
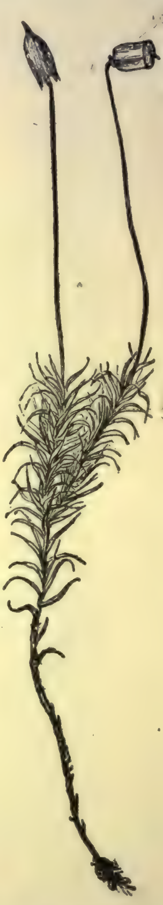


FIG. 172.—Developing sporophyte of a moss: *A*, young sporophyte developed from egg in archegonium; *B* and *C*, more advanced stages, in which the sporophyte is elongating and becoming anchored in the leafy plant.—After GOEBEL.



sporophyte

Gametopl

FIG. 173.—A common moss-bearing mature sporophytes, which are long-stalked spore-cases.—After SCHENCK.

It must be remembered, however, that the sperms are very small and can swim in such a film of water as may be left on the plant by a heavy dew or rain. Since many mosses grow in very dry places, fertilization with them must be very infrequent. When the sperms are free to swim they are attracted toward the necks of the archegonia, pass down them, reach the egg, and fertilization is accomplished.

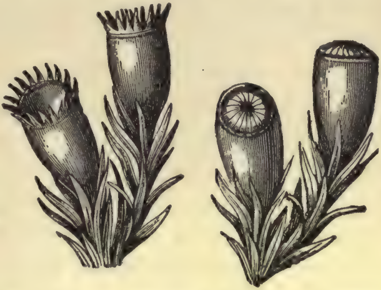


FIG. 174.—Spore-cases of a moss, from which the lids have fallen, displaying the teeth. —After KERNER.

The oöspore thus formed within the archegonium at once begins to germinate (Fig. 172), and forms the spore-producing structure, which in mosses is much more than a

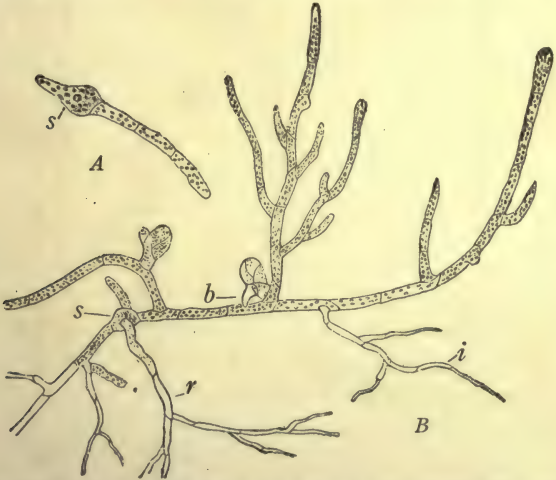


FIG. 175.—Filamentous growth of the young moss: *A*, very young filament coming from a spore (*s*); *B*, older filament, showing branching habit, remains of old spore (*s*), rhizoids (*r*), and buds (*b*) which develop the erect leafy branches.—After MUELLER-THURGAU.

spore-case. It has a long slender stalk, which becomes anchored in the stem of the leafy plant (Fig. 172); and the stalk bears an elaborate and usually urn-shaped spore-case full of spores (Fig. 173). This spore-case opens by means of a lid, which drops off; and often at the mouth of the urn thus opened there may be seen a set of delicate teeth extending from the margin of the rim and meeting in the center (Fig. 174). These teeth bend inward and outward as they are dry or moist, and help discharge the spores. It is evident that this spore-case with its anchored stalk is the sporophyte generation in the life-history.

When the spores fall in suitable situations they germinate, and each one produces a green branching filament that looks like one of the filamentous green Algæ (Fig. 175). This branching filamentous growth spreads over the substratum, and presently there appear upon it buds (Fig. 175, *B*, *b*), each of which develops an erect leafy stem, which is recognized as a new leafy moss plant, the form with which this account of the life-history was begun.

103. **Alternation of generations.**—In the life-history just given, it is evident that the prostrate green filament and the erect leafy stems are two parts of the gametophyte; for the leafy stems simply arise as erect branches from the prostrate filament. It is strictly true, therefore, that the so-called moss plant, the conspicuous part of the moss, is a leafy branch of the gametophyte. These leafy branches become independent of the filament by sending out rhizoids into the substratum, so that it is only by actually germinating the spores that the filaments are seen. Not only does this branch bear leaves, and hence perform the chief work of food manufacture, but it also bears the sex-organs.

The sporophyte, on the other hand, is dependent upon this leafy branch for its food-supply, and in that sense may be said to be parasitic upon it. Its only work is to produce spores; while the gametophyte does the chlorophyll work and also produces the sex-organs. The life-history, with its alternating generations, may be indicated as follows:

$$G\left(\begin{matrix}\text{filament and}\\\text{leafy branch}\end{matrix}\right)\begin{matrix}\text{—o}\\\text{—o}\end{matrix}>\text{o—}S\left(\begin{matrix}\text{stalked}\\\text{spore-case}\end{matrix}\right)\text{—o—}G\begin{matrix}\text{—o}\\\text{—o}\end{matrix}>\text{o—}S\text{—o—}G,$$

etc.

104. **The great groups of Mosses.**—There are two great groups of mosses, known as the *bog mosses* and the *true mosses*. The bog mosses are large and pallid mosses found abundantly in bogs and marshy ground, and are the most conspicuous peat formers. They differ from the true mosses in structure in many ways that need not be mentioned, but one contrasting character deserves attention. When the spore of a bog moss germinates, it does not produce a branching green filament, but a flat compact thallus body like that of the liverworts. On this thallus body the erect leafy branches arise, just as they do from the filamentous body in true mosses. This is interesting, because in the bog mosses the thallus body of the liverworts is continued, and also because it indicates that the prostrate filamentous body of the true mosses is probably a modified thallus body.

The true mosses are much more numerous than the bog mosses, and live in a far greater variety of situations. Some of them are also peat formers, but most of them have become established in much drier situations.

105. **The erect leafy axis.**—The lowest green plants live in the water or in very moist places, but the liverworts begin to occupy the land. In this new position they are better exposed to light, which is an advantage in food manufacture; but they are in danger of being dried out by the air. In consequence of these dangers, various protective structures have been developed, one of the first being a compact body with an epidermis. An exposure of more green tissue to the light is secured by the leafy liverworts in their development of leaves, but their bodies are prostrate

and the best exposure is not obtained. The mosses have made still further progress in developing an erect branch upon which leaves are spread out to the light and air freely in all directions. All this advance has been made by the gametophyte, which in the mosses has reached the best position for leaves and hence for food manufacture. How progress in this direction is carried further by the higher plants will be seen in subsequent chapters.

CHAPTER X

FERNS

106. **Summary.**—Before studying the ferns, it is well to note the progress that has been made by the plants previously considered. It has been said that the Algæ and Fungi together form the first great division of the plant kingdom, the *Thallophytes.* The liverworts and mosses together form the second great division, called the *Bryophytes,* a name meaning "moss plants." The ferns introduce the third great division, called the *Pteridophytes,* which means "fern plants." A summary of the contributions made by the Bryophytes to the progress of plants is as follows:

(1) *The land habit.*—The Bryophytes establish green plants upon the land, and as a consequence begin to develop those structures that the new conditions demand.

(2) *Alternation of generations.*—A life-history consisting of alternating sexual (gametophyte) and sexless (sporophyte) generations is finally established, although it is indicated in the life-histories of certain Thallophytes.

(3) *Gametophyte the chlorophyll generation.*—In the alternation the gametophyte generation develops the chloroplasts for food manufacture, and on this account is the conspicuous generation. When a moss or a liverwort is spoken of, therefore, the gametophyte is usually referred to.

(4) *Sporophyte dependent.*—The sporophyte in the Bryophytes is dependent upon the gametophyte for food, and hence remains attached to it. Only by the *Anthoceros* forms has a partial independence of the sporophyte been attained.

(5) *Appearance of leaves.*—Among the Bryophytes very simple leaves are developed by the gametophyte, and the mosses produce leaves upon an erect stem.

(6) *Many-celled sex-organs.*—The many-celled antheridia and flask-shaped archegonia are very characteristic of Bryophytes, and distinguish even the thallose forms from any Thallophytes.

107. **General characters of Ferns.**—The ferns are well-known plants, and the ordinary forms are easily recognized (Fig. 176). In fact, the general appearance of the large compound leaves is so characteristic that when a leaf is said to be fern-like a particular appearance is suggested. Al-

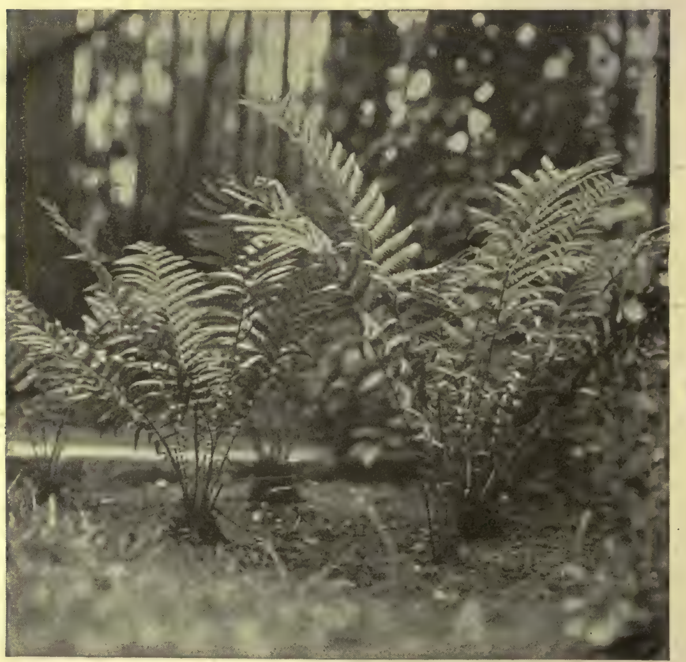


FIG. 176.—Shield ferns.

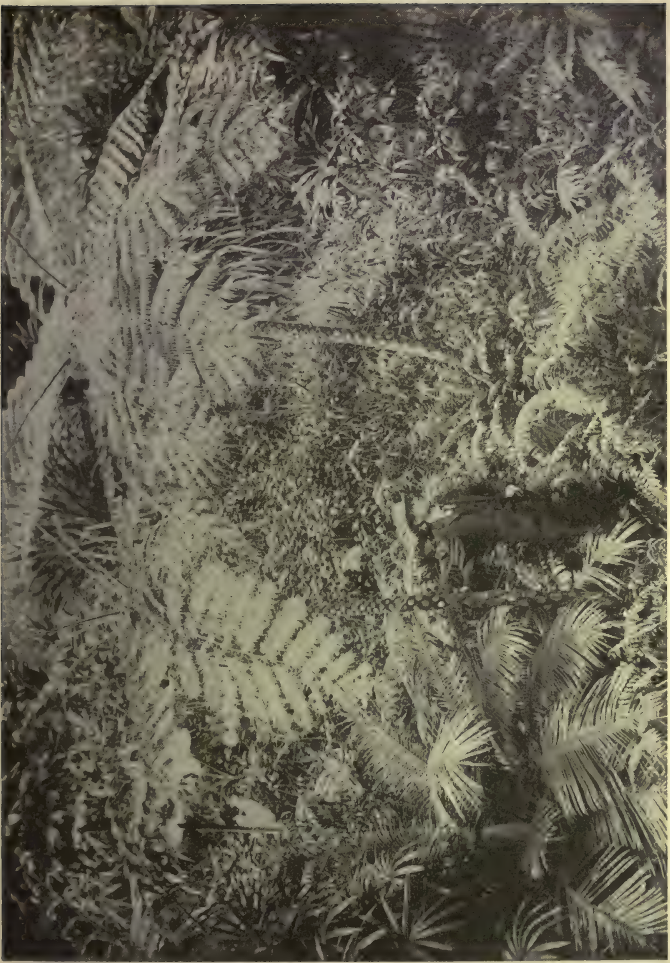


FIG. 177.—Tree ferns.—Photograph by RITCHIE.

though ferns are found in considerable numbers in temperate regions, their chief display is in the tropics, where they form a striking and characteristic feature of the vegetation. In the tropics not only are great masses of the low forms to be seen, from those with delicate and filmy moss-like leaves to those with huge leaves, but also tree forms with cylindrical trunks encased by the rough remnants of fallen leaves and sometimes rising to a height of thirty-five to forty-five feet, with a crown of great leaves fifteen to twenty feet long (Fig. 177). There are also air forms (Fig. 178), that is, ferns that perch upon other plants but

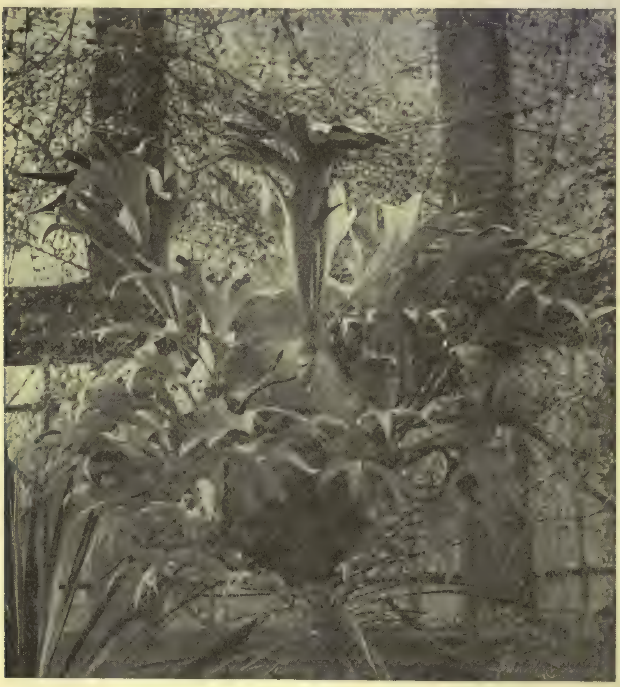


FIG. 178.—The staghorn fern, which is an epiphyte.

derive no nourishment from them (§ 41). This habit belongs chiefly to the moist tropics, where plants may obtain sufficient moisture from the air without sending roots into the soil.

108. **Sporophytes.**—If an ordinary fern be examined, it will be discovered that it has a horizontal underground stem or rootstock (§ 27), which sends out roots into the soil, and one or more large leaves into the air (Fig. 179). These leaves, appearing to come directly from the soil, were once supposed to be different from ordinary leaves and were called *fronds;* but although the name is still used in connection with fern leaves, it is neither necessary nor accurate. These leaves are usually compound, branching either pinnately or palmately.

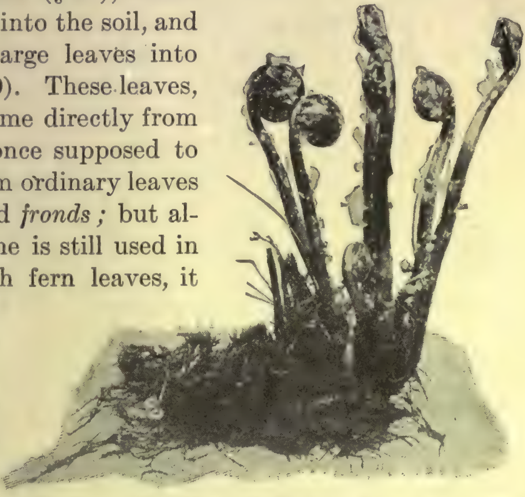


FIG. 179.—The habit of an ordinary fern (sporophyte), showing the horizontal rootstock sending out roots and leaves, and also the peculiar rolled tip of the developing leaves.

There are two peculiarities about fern leaves that should be noted. One is that in expanding the leaves seem to unroll from the base, as though they had been rolled from the apex downward, the apex being in the center of the roll. When unrolling, this gives the leaves a crozier-like tip (Fig. 179). The other peculiarity is that the veins fork repeatedly (Fig. 180). This combination of unrolling leaves and forking veins is very characteristic of ferns.

Probably the most important fact about the fern body is that it contains a vascular system (§ 24) (Fig. 181). The appearance of this system marks some such epoch in the evolution of plants as is marked among animals by the appearance of the backbone. As animals are often grouped as vertebrates and invertebrates, so plants are often grouped as vascular plants and non-vascular plants, the latter being the Thallophytes and the Bryophytes, the former the ferns and the seed-plants. The presence of this vascular system means a special conducting system, and in connection with it there are developed the first roots and the first complex leaves. Such a plant body, with its vascular system and roots and complex leaves, is so different from any plant body among Bryophytes that the greatest gap in the whole series of plants, from lowest to

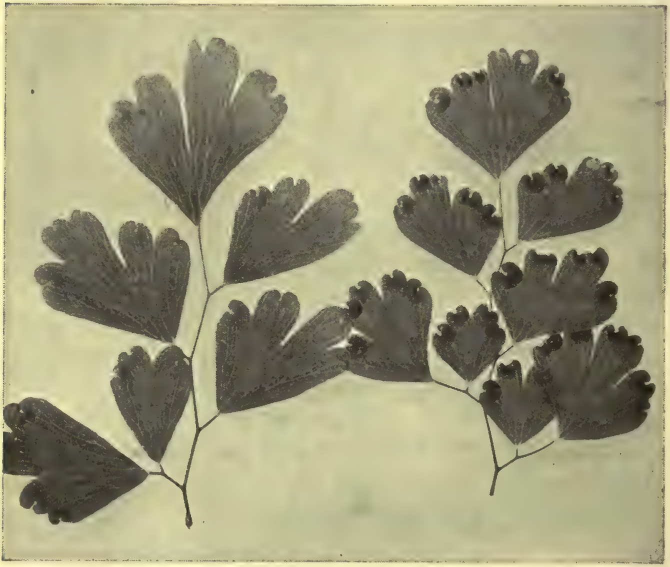


FIG. 180.—Portion of the leaf of maidenhair fern, showing the forking veins.

highest, is felt to be the one between Bryophytes and Pteridophytes. On account of the vascular system and other resistant structures, the remains of ferns have been preserved in great abundance in the rocks. These records show that the ferns are a very ancient group, occurring in special abundance during the Coal-measures.

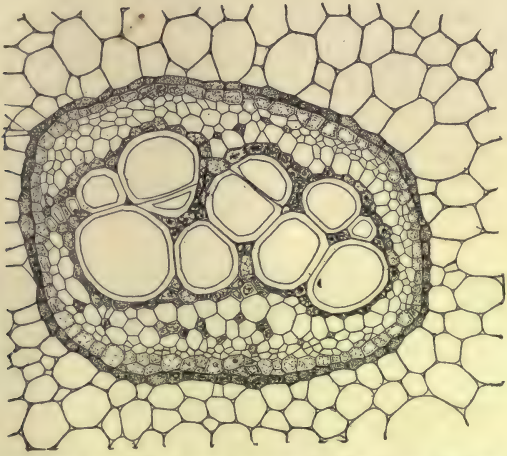


Fig. 181.—Cross-section of the stem (rootstock) of a fern, showing the peculiar vascular axis, the large xylem vessels being completely surrounded by the phloem.

Another striking fact about this leafy body of the ferns is that it never produces sex-organs, but does produce spores abundantly. This means that it is the sporophyte in the life-history of the fern, and when it is contrasted with the sporophyte of Bryophytes the differences are remarkable. Among the liverworts and the mosses the sporophyte is a leafless structure attached to the gametophyte and dependent on it, while the gametophyte is the leafy body doing chlorophyll work. Among the ferns, however, the sporophyte is an elaborate leafy structure and entirely independent. Therefore, when one ordinarily speaks of a moss and a fern, the gametophyte is referred to in the former case and the sporophyte in the latter. This means that, in passing from mosses to ferns, plants have transferred the chief work of food manufacture from the gametophyte to the sporophyte, which has thus become the conspicuous generation. The leaves of mosses, therefore, are gametophyte leaves; while the leaves of ferns are the first sporophyte leaves. A common and brief statement of the contrast between the two groups is that mosses have a leafless and ferns a leafy sporophyte. How the leafless sporophyte has become a leafy one is an interesting but un-

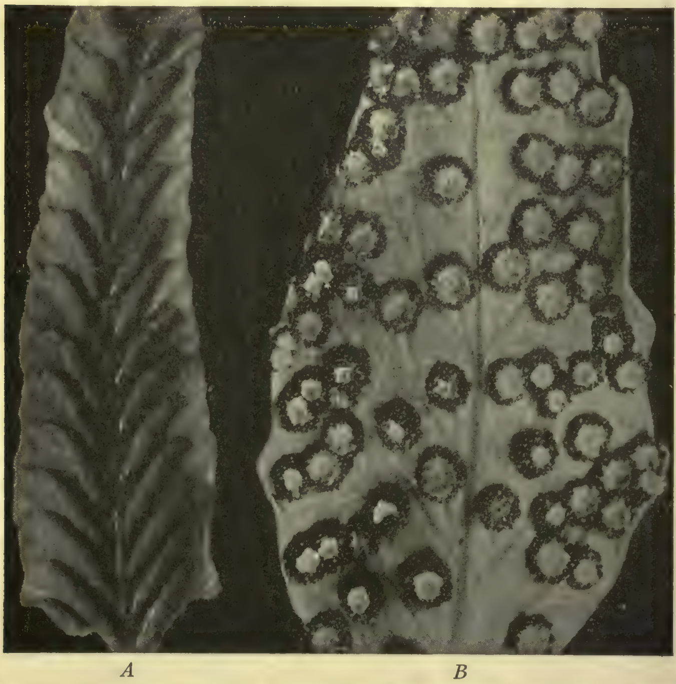


FIG. 182.—Sporangia of ferns: *A*, elongated sori, with pocket-like indusia; *B*, round sori, with shield-like indusia.

answered question. The great interest of the *Anthoceros* forms (§ 99) is due to the fact that their sporophytes are green and do chlorophyll work; and this has suggested the thought that from such green tissue leaves have been developed, and thus a leafy sporophyte has been started.

109. **Sporangia.**—Upon the under surface of fern leaves dark dots or lines are often seen (Fig. 182). These are groups of sporangia, usually occurring along the veins of the under surface, but sometimes in long lines along the edge, the margin of the leaf rolling in and protecting them, as in maidenhair fern and common brake (Fig. 183). In ferns having the groups of sporangia away from the margin, each group (*sorus*) is usually protected by a delicate flap (*indusium*) growing out from the epidermis, sometimes forming a pocket (Fig. 182, *A*) and sometimes an umbrella-like or shield-like covering (as in shield ferns) (Fig. 182, *B*). The position and the shape of the sorus and the character of the indusium furnish useful characters in the classification of ferns.

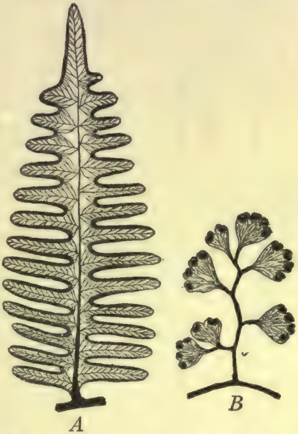


FIG. 183.—Sporangia of ferns, showing marginal lines of sporangia protected by the inrolled margin of the leaf: *A*, the common brake; *B*, maidenhair fern.

Most fern leaves do chlorophyll work and produce sporangia, two very distinct kinds of work. In some ferns, however, some of the leaves are sterile, that is, do not produce sporangia, the other leaves doing both kinds of work; while in other ferns certain leaves or leaf branches are set apart to produce sporangia and do no chlorophyll work, and *vice versa*, the two kinds of work thus being divided among the leaves or leaf branches. Such a division of work occurs in the royal fern, climbing fern, ostrich fern, sensitive fern, moonwort (Fig. 184), adder's tongue, etc.

The sporangium of an ordinary fern consists of a spore-case with a slender stalk (Fig. 185). The case has a delicate wall formed of a single layer of cells; and, extending around it from the stalk and nearly to the stalk again, like a meridian line about a globe, is a row of peculiar cells with thick walls, forming a heavy ring. This ring is like a bent spring; and when the delicate wall begins to yield, the spring straightens violently, the wall is torn, and as the spring rebounds the spores are hurled with considerable force, like a handful of pebbles thrown forward from the hand. This discharge of spores may be seen by placing some mature sporangia upon a moist

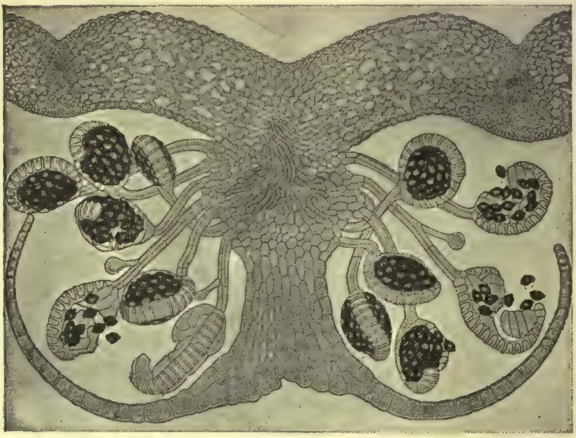


FIG. 185.—Section through the sorus of a shield fern, showing indusium and sporangia.—After ENGLER and PRANTL.

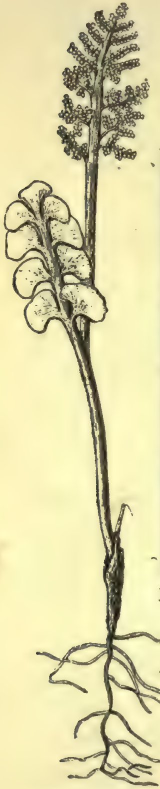


FIG. 184.—A moonwort, showing foliage and sporangium-bearing branches of a leaf.—After STRASBURGER.

slide, and under a low power watching them as they dry and burst.

110. **Gametophytes.**—In continuing the life-history of a fern, the spores when discharged, as just described, begin to germinate, provided they have reached suitable conditions. Each germinating spore produces a green thallose body that resembles a very small delicate liverwort (Fig. 186). It is deeply notched, having a general heart-shaped outline, and is usually less than one-fifth of an inch in diameter. This thallus is so thin that all its cells contain chloroplasts, and rhizoids from the under surface anchor it to the soil. It is evident that it is an independent plant, although a very small one. Upon this minute plant the sex-organs are produced, and therefore it is the gametophyte in the life-history. This fern gametophyte, because it is a thallus body which precedes the appearance of the large sporophyte, has been called the *prothallium* (or *prothallus*), and this name has come to be very commonly used for gametophyte among all the higher plants. At the bottom of the conspicuous notch of the prothallium is the growing point, representing the apex of the plant.

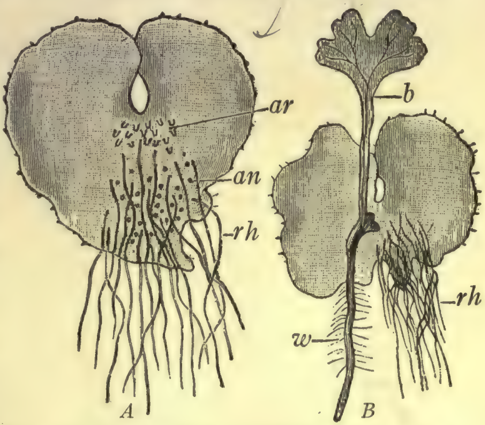


FIG. 186.—Gametophyte (prothallium) of a fern: *A*, under surface showing rhizoids (*rh*), antheridia (*an*), and archegonia (*ar*); *B*, under surface of an older gametophyte, showing the young sporophyte, with root (*w*) and leaf (*b*).—After SCHENCK.

The antheridia and the archegonia are produced on the under surface of the prothallium in the region of the central axis. When the prothallia are very young, the antheridia begin to appear; and if the prothallia are poorly nourished and stunted only antheridia appear. In mature, well-nourished prothallia, however, archegonia also appear. In consequence of their late appearance, the group of archegonia is near the notch, that is, near the growing point, while the group of antheridia is farther back, on the older part of the prothallium (Fig. 186, *A*).

The antheridia and the archegonia are not free and projecting organs, as among the Bryophytes, but they are more or less sunken in the tissue of the prothallium and open on its surface. In the case of the archegonium only the neck projects, and this is usually bent backward toward the antheridia (Fig. 187). The egg resembles those of all other archegonium-bearing plants; but the sperms are very different from those of Bryophytes, having large

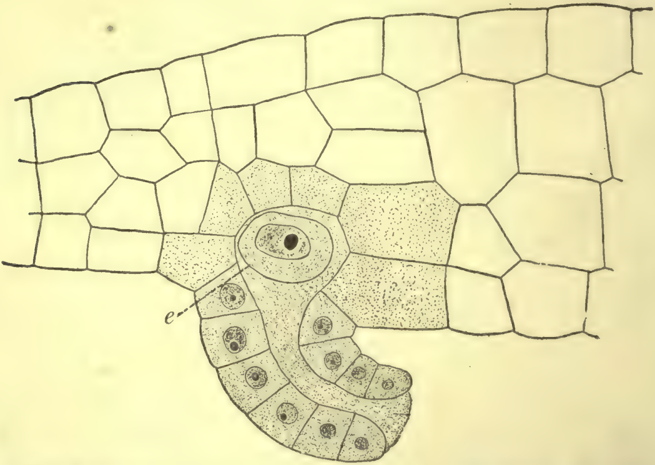


Fig. 187.—Archegonium of a fern containing an egg (*e*), the neck being curved backward toward the antheridia.

spirally coiled bodies, blunt behind and tapering to a beak in front, the beak bearing numerous cilia (Fig. 188). The fern sperm, therefore, is a large, spirally coiled, multiciliate sperm, as compared with the small biciliate sperm of Bryophytes.

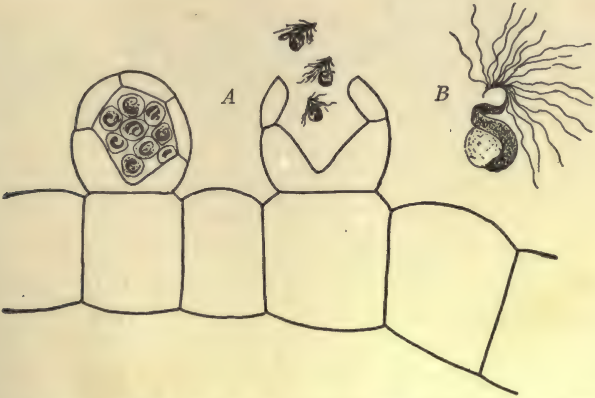


FIG. 188.—Two antheridia of a fern (*A*), one containing sperms, the other discharging them; also a single sperm much enlarged (*B*).

With a ciliated sperm, fertilization can be effected only in the presence of moisture, and if prothallia are kept dry fertilization does not occur. In nature, however, the prothallia lying prostrate on the substratum are in a favorable position for moisture; and when there is a film of moisture between the prothallium and the substratum the sperms can swim to the archegonia.

The oöspore which is produced germinates at once and forms the leafy sporophyte (Fig. 186, *B*). The young stem and the root remain under the soil, but the young leaf is seen curving upward through the notch of the prothallium and growing up into the air and light. For a short time the young plantlet absorbs nourishment from the prothallium, but with its own root system and leaves it soon becomes independent. In fact, the prothallium is so small, and the leafy sporophyte becomes relatively so large, that the dependence of the latter upon the former is a very small item in the life-history.

111. **Alternation of generations.**—The contrast between the alternating generations of mosses and the same generations in ferns is striking. In mosses the gametophyte is the conspicuous phase in the life-history, with its prostrate filaments and leafy branches; while in ferns the gametophyte (prothallium) is a very inconspicuous phase in the life-history, being seen only by those who know what to look for, and resembling a very small simple liverwort. In the mosses the sporophyte is at most only a stalked spore-case, attached to the gametophyte and dependent upon it for nourishment; while in ferns the sporophyte is a large, independent, leafy plant, with vascular system and roots.

The formula for the life-history of a fern may be written as follows:

$$G(\text{prothallium})\begin{smallmatrix}\text{—o}\\ \text{—o}\end{smallmatrix}>\text{o}\text{—}S(\text{leafy plant})\text{—o—}G\begin{smallmatrix}\text{—o}\\ \text{—o}\end{smallmatrix}>\text{o}\text{—}S\text{—o—}\mathrm{G},$$

etc.

CHAPTER XI

HORSETAILS AND CLUB-MOSSES

HORSETAILS

112. General characters.—The horsetails or equisetums are represented today by only twenty-five species; but during the Coal-measures the species were very numerous, and some of them were great trees, forming a conspicuous part of the forest vegetation. They grow in moist or dry ground, sometimes in great abundance, and have such a characteristic appearance that they cannot be mistaken.

The stem is slender and conspicuously jointed, the joints separating easily (Fig. 189).

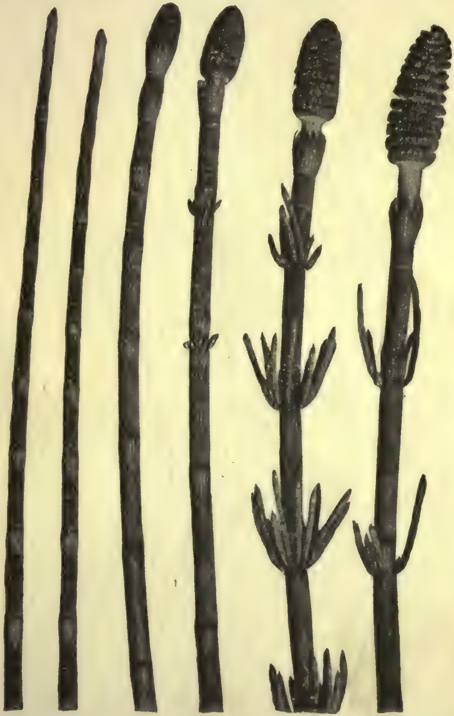


FIG. 189.—*Equisetum:* showing the jointed and fluted stem, the sheath of minute leaves at each joint, strobili in various stages, and some young branches.

It is also green, and fluted with small longitudinal ridges; and there is such an abundant deposit of silica in the epidermis that the plants feel rough. This last property suggested formerly its use in scouring, and the name "scouring rush." At each joint there is a sheath of minute leaves, more or less coalesced, the individual leaves sometimes being indicated only by minute teeth. This arrangement of leaves in a circle about the joint is the *cyclic* arrangement, the leaves being said to be *whorled* (§ 8). These leaves contain no chlorophyll and have evidently abandoned food manufacture, which is carried on by the green stem; hence they are scales rather than foliage leaves. The aerial stem, which arises from an elongated rootstock, is either simple or profusely branched. In some cases the aerial stems early in the season are simple, usually not green, and bear the sporangia (Fig. 190); while the later branches from the same rootstock are sterile, profusely branched, and green (Fig. 191).

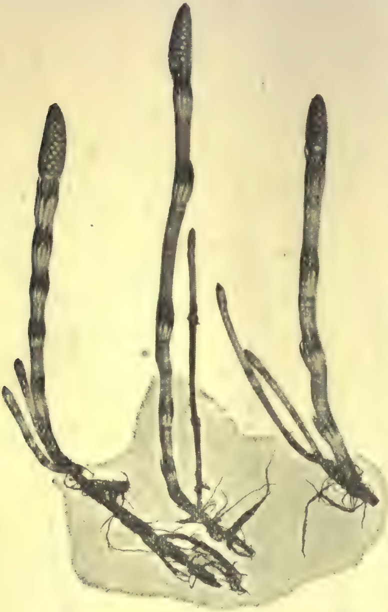


FIG. 190.—Early fertile shoots of *Equisetum*, which are not green, have conspicuous leaf-sheaths at the joints, and bear conspicuous strobili; beginnings of the later sterile shoots also seen.

113. **Strobilus.**—At the apex of the aerial stem there may be found a more or less conspicuous cone-like structure, called the *strobilus*, meaning "pine cone," which it resembles in general outline (Fig. 190). The strobilus is a com-

pact group of modified leaves bearing sporangia. · Just as in some ferns certain leaves are set apart to do chlorophyll work and others to bear sporangia, so in the *Equisetum* the same division of work occurs; but the notable thing is that the sporangium-bearing leaves are massed together in a cluster that is quite distinct from the rest of the plant. Leaves set apart for bearing sporangia are called *sporophylls*, which means "spore leaves.' A strobilus, therefore, is a group of sporophylls that form a more or less distinct cluster, distinct from the rest of the plant.

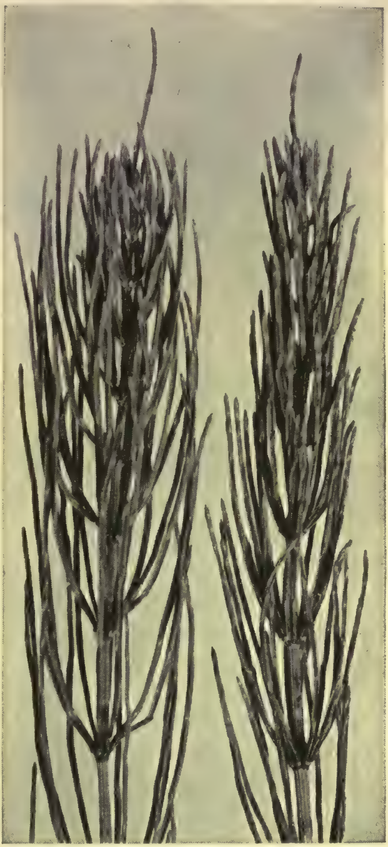


FIG. 191.—Later sterile shoots of the species shown in Fig. 190, and photographed a month later.

In *Equisetum* each sporophyll consists of a stalk-like portion and a shield-like top, beneath which the several sporangia hang (Fig. 192, *A*). The spores have a very peculiar outer wall. It consists of two spiral bands wound about the spore and fastened to it only at the point where they intersect (Fig. 192, *B*). When dry, the bands loosen and uncoil; when moistened, they close around the spore. The coiling and uncoiling movements of these bands as they are wet or dry entangle the spores, and they fall in clumps, a number of them thus germinating close together.

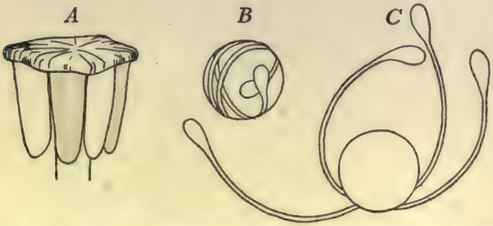


FIG. 192.—*A*, a sporophyll of *Equisetum*, bearing sporangia beneath the shield-like top; *B* and *C*, spores, showing the unwinding of the two bands forming the outer coat.

114. **Gametophyte.** — When the spores of an *Equisetum* germinate they give rise to gametophytes that in all general features resemble those of the ferns; that is, they are small, green thallus bodies producing antheridia and archegonia. From the oöspores produced in the archegonia the large sporophyte arises, with its roots, rootstock, branches, leaves, and strobili.

It is evident that, although an *Equisetum* does not seem to resemble a fern in the least, the life-history and the character of the alternating generations are the same.

CLUB-MOSSES

115. **General characters.**—The club-mosses often look like coarse mosses, as the name suggests. Some of the larger ones are called also ground pines, because of a certain resemblance to miniature pines. They are slender branching plants, with the prostrate or erect stems completely clothed with small leaves (Fig. 193). The larger and coarser forms are abundant in the Northern woods, the prostrate stems often trailing extensively and giving rise to erect branches. The more delicate forms are abundant in the tropics, and are very common in greenhouses as decorative plants.

During the Coal-measures the club-mosses occurred in great abundance, and among them were large trees of various kinds, forming a very prominent part of the forest vegetation. As in the case of the equisetums, therefore, the club-mosses, or *Lycopods* as they are called, were once

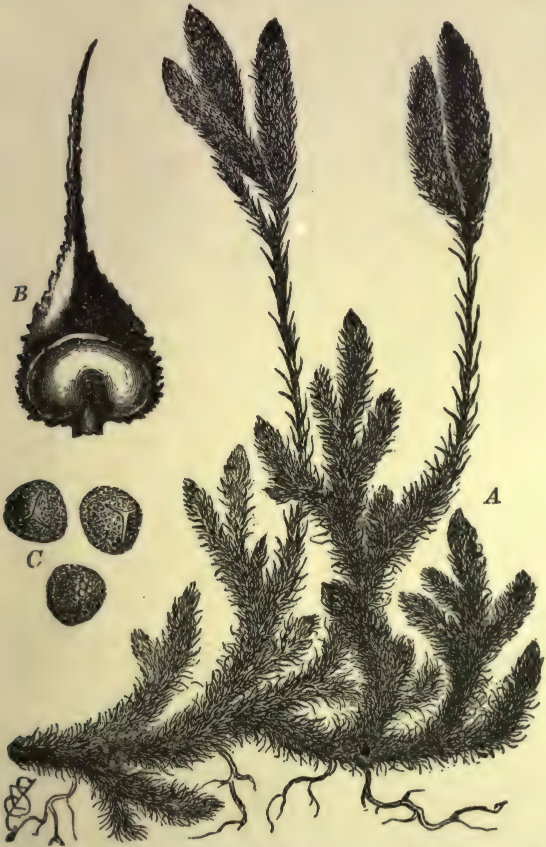


FIG. 193.—*Lycopodium: A*, the whole plant, showing the horizontal stem giving rise to roots and erect branches bearing strobili; *B*, a single sporophyll with its sporangium; *C*, spores much magnified.—After WOSSIDLO.

far more conspicuous plants than they are now, and only the smaller forms have persisted to the present time.

116. **Strobili.**—One of the conspicuous features of the lycopods is the cylindrical strobilus, which usually terminates the erect branches, and is the "club" that enters into the name club-moss (Fig. 193, *A*). Sometimes the strobilus is quite distinct from the rest of the stem; and sometimes it cannot be distinguished from it, so that there is no external indication where leafy stem ends and strobilus begins.

The leaves of the strobilus resemble the ordinary foliage leaves; but each one is a sporophyll, bearing a single large sporangium on its upper surface at the base (Fig. 193, *B*), so that the sporangium appears in the axil of the sporophyll. Among the ferns the sporangia are numerous on the under side of leaves; among equisetums they are several on the under side of sporophylls; among lycopods they are solitary on the upper side of sporophylls.

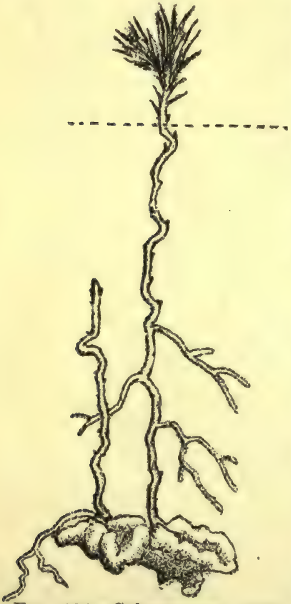


FIG. 194.—Subterranean gametophytes of *Lycopodium*, showing their irregular, tuberous form; the dotted line represents the surface of the soil.—After BRUCHMANN.

117. **Lycopodium.**—The *Lycopodium* forms are chiefly the coarse club-mosses of temperate regions, and are mostly spoken of as the large club-mosses. The strobili are often conspicuous and very distinct from the rest of the plant. This leafy, branching plant with its strobili is, of course, the sporophyte (Fig. 193, *A*). When its spores germinate they produce gametophytes; but these gametophytes, instead of being green, prostrate, thallose bodies,

as are the gametophytes (prothallia) of ferns and equisetums, are subterranean tuberous bodies with no chlorophyll, on which the antheridia and archegonia appear (Fig. 194). In some forms of *Lycopodium* the tuberous prothallium develops an aerial portion that is green and bears the sex-organs. This strange subterranean and saprophytic prothallium is in marked contrast with the prothallia of ferns in its habits and appearance.*

118. Selaginella.—The *Selaginella* forms are much more numerous than the *Lycopodium* forms, being especially abundant in the tropics, and are often called the little club-mosses on account of their smaller size and more delicate texture. It is these forms that are common in greenhouses as decorative plants. There are often no strobili very distinct from the leafy stem, the solitary sporangia occurring in the axils of the upper leaves (Fig. 195).

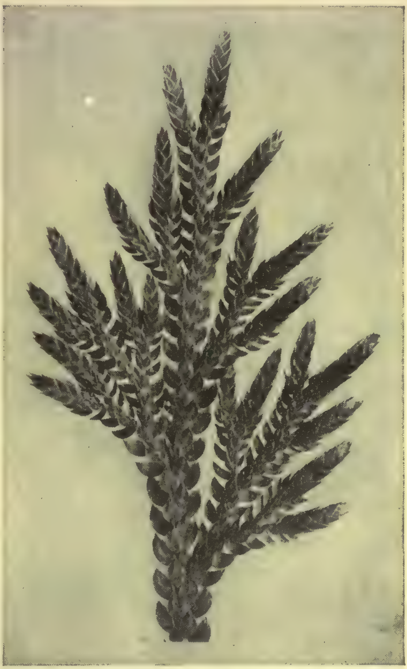


FIG. 195.—Branch of *Selaginella* bearing strobili.

The most important fact in connection with *Selaginella* is that all the sporangia in a strobilus do not produce the same kind of spores. For example, certain sporangia (usually the lower ones) may each contain four large spores (Fig. 196, *C* and *D*), while the other sporangia contain very numerous and very much smaller spores (Fig. 196, *A* and *B*). There may be no difference in the appearance of the sporangia. A plant that produces two kinds of spores, differing in size, is said to be *heterosporous* (spores different). The appearance of this condition is a very important fact, for it is an introduction to the appearance of the higher plants.

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* The gametophytes of *Lycopodium* are so rarely found that it is not expected that they will be seen by the student.

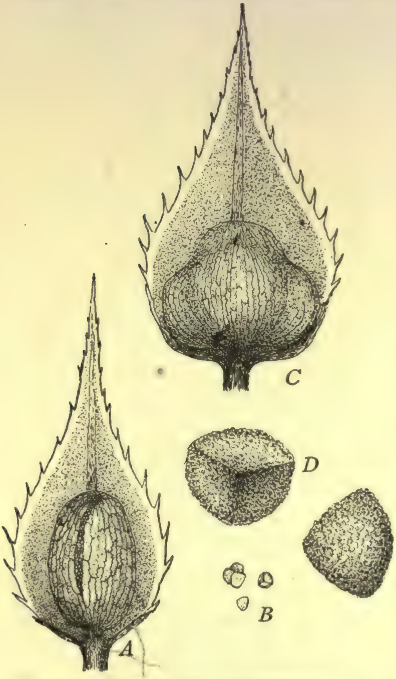

Fig. 196.—Sporophylls of *Selaginella: A*, sporophyll bearing sporangium that produces numerous small spores (*B*); *C*, sporophyll bearing sporangium that produces few large spores (*D*).

Difference in the size of spores does not seem important; but when this is accompanied by difference in the gametophytes produced, it is very important. When the small spore germinates, it produces a few-celled gametophyte, so small that it is contained entirely within the old spore wall. This gametophyte produces one antheridium, and this antheridium forms the bulk of the whole body. Therefore, the small spore produces a very small male gametophyte. When the large spore germinates, it produces a many-celled gametophyte, which bursts through the spore wall and becomes partly exposed. In this exposed part archegonia appear, and therefore the large spore produces a female gametophyte (Fig. 197).

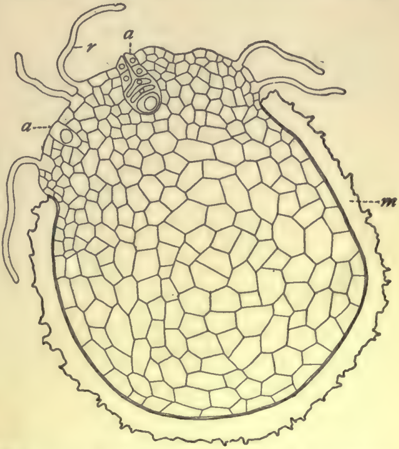

FIG. 197.—Female gametophyte of *Selaginella*, having burst through the wall of the megaspore (*m*), and bearing archegonia (*a*) and rhizoids (*r*) upon its exposed part; somewhat diagrammatic.

In *Selaginella*, therefore, the two kinds of sex-organs are produced by different plants, and we speak of male and female gametophytes. The connection of these two kinds of gametophytes with the two kinds of spores must be kept clear. The small spore (*microspore*) produces the male gametophyte, and the large spore (*megaspore*) produces the female gametophyte. It must be remembered, also, that with this change the gametophytes have become much smaller than they were before, and are no longer independent, in the sense of doing chlorophyll work.

It follows that in the life-history of *Selaginella* there is an alternation of the sporophyte with two gametophytes. How this contrasts with the life-history of an ordinary fern may be indicated as follows:

$$\text{Fern: } G\begin{matrix}\text{—o}\\ \text{—o}\end{matrix}\!>\text{o—S—o—}G\begin{matrix}\text{—o}\\ \text{—o}\end{matrix}\!>\text{o—S—o—}G\begin{matrix}\text{—o}\\ \text{—o}\end{matrix}\!>\text{o—S, etc.}$$

$$\text{Selaginella: } \begin{matrix}\text{G—o}\\ \text{G—o}\end{matrix}\!>\text{o—S}\begin{matrix}\text{—o—G—o}\\ \text{—o—G—o}\end{matrix}\!>\text{o—S}\begin{matrix}\text{—o—G—o}\\ \text{—o—G—o}\end{matrix}\!>\text{o, etc.}$$

119. **Coal.**—The ferns, equisetums, and lycopods were associated together during the Coal-measures, and were the most conspicuous plants in the formation of coal. The formation of peat, already referred to (§ 101), indicates the

first stages in coal-formation. During the Coal-measures there were very extensive areas of swampy land covered with a luxuriant vegetation, consisting principally of ferns, equisetums, and lycopods. The dead bodies of these plants accumulated in immense deposits in the swamp waters; and when a sinking of the land brought it under water, sediments were deposited upon the accumulated vegetation and it was gradually changed into coal. Successive risings and sinkings of the land surface brought about an alternation of vegetation and sediments, and so the coal lies in beds of varying thickness. The ferns, equisetums, and lycopods are often spoken of as peculiarly useless plants; but when one considers the part they played in coal-formation, and the importance of coal in our civilization, it is evident that no plants have done more for human welfare.

The different kinds of coal depend upon the amount and kind of changes in this old buried vegetation. For example, hard coal (anthracite) has been changed most, containing eighty-five per cent or more of carbon; while soft (bituminous) coal contains only fifty to seventy-five per cent of carbon. It will be remembered that green plants take carbon dioxide from the air and use the carbon in building their bodies (§ 14). Therefore, the enormous amount of carbon contained in coal deposits was in the main drawn from the air by plants. When coal is burned now there is made a tardy return of carbon dioxide to the air for that which was taken from it millions of years ago.

The coal-fields of the United States are the greatest in the world that are now being worked; but the coal-fields of China are probably even greater. The coal of the United States is all soft coal, except in the mountain region of Pennsylvania, where the bituminous coal has been changed into anthracite.

CHAPTER XII

GYMNOSPERMS

120. **Summary.**—The ferns, equisetums, and lycopods are representatives of the third great division of the plant kingdom, the *Pteridophytes* (fern plants). Their contributions to the progress of plants are very important and may be summarized as follows:

(1) *Leafy sporophytes.*—All Pteridophytes have leafy sporophytes, and all Bryophytes have leafless ones, so that this change is not only great, but also complete. The leafy sporophyte means also a *vascular system* and *roots*, and therefore these structures are introduced by the Pteridophytes.

(2) *Sporophylls.*—The setting apart of certain leaves to bear sporangia makes a division of work between foliage leaves and sporophylls, and the arrangement of the sporophylls into the distinct cluster known as the *strobilus* marks another advance.

(3) *Heterospory.*—The occasional appearance of heterosporous plants among Pteridophytes, as *Selaginella* and a few other forms, is noteworthy, because all the plants of the next and highest group are heterosporous. Associated with heterospory is a great reduction in the size of the two gametophytes, which are so small that they project little if at all from the spores which produce them.

121. **The four great plant groups.**—Three of the great divisions of the plant kingdom have been considered. The

fourth differs from them all in producing seeds, and hence is called *Spermatophytes* or seed-plants. It may be well to give certain prominent characters that will serve to distinguish these four primary groups. It must not be supposed that these are the only characters, or even the most important ones in every case, but they are convenient for our purpose.

(1) *Thallophytes.*—Thallus body, but no archegonia.
(2) *Bryophytes.*—Archegonia, but no vascular system.
(3) *Pteridophytes.*—Vascular system, but no seeds.
(4) *Spermatophytes.*—Seeds.

It will be noticed that for each of the first three groups two characters are given, one a positive character that belongs to it, the other a negative character that distinguishes it from the group above, and becomes the positive character of that group. For example, thallus bodies are found among Bryophytes, and the prothallium of a Fern is a thallus body; but plants whose thallus bodies do not bear archegonia are Thallophytes. Also, archegonia are produced by Pteridophytes as well as by Bryophytes, but archegonium-bearing plants without a vascular system can be only Bryophytes. Both Pteri-

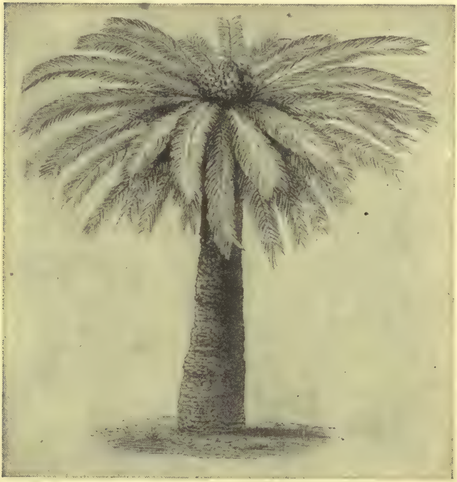

FIG. 198.—A cycad with columnar stem.—After STRASBURGER.

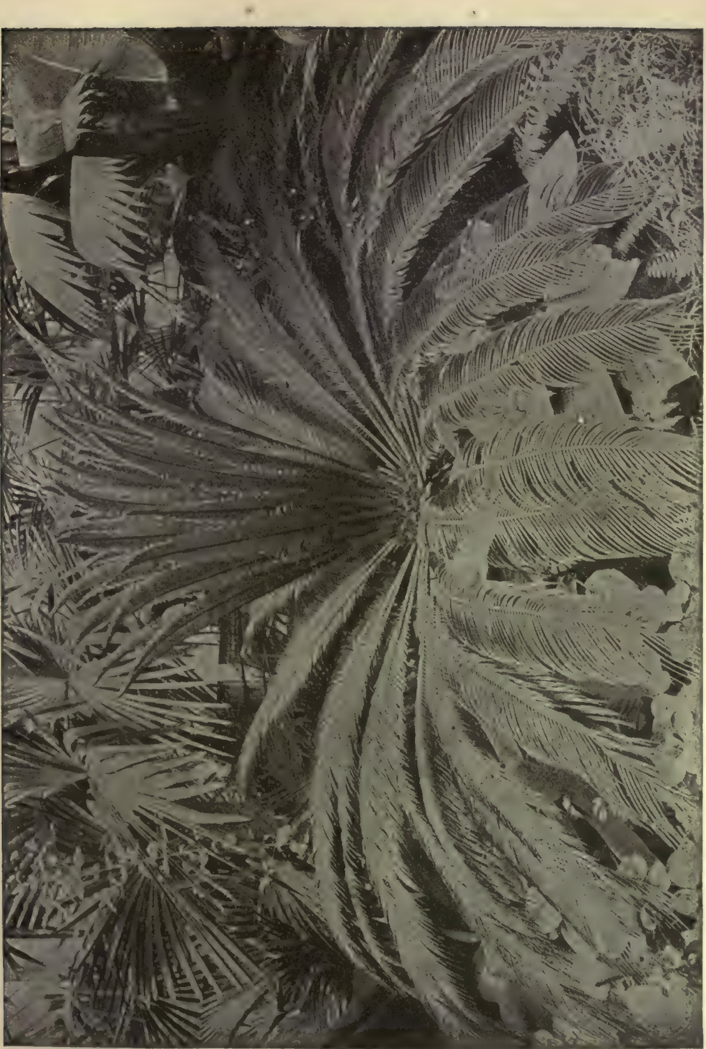

FIG. 199.—The crown of foliage at the summit of a columnar cycad.

dophytes and Spermatophytes have vascular systems, but only the latter produce seeds.

122. **General characters of Gymnosperms.**—The Gymnosperms are one of the two groups of seed-plants, the most familiar ones in temperate regions being pines, spruces, hemlocks, cedars, etc., the group commonly called evergreens. It is an ancient group, for its representatives were associated with the giant club-mosses and horsetails in the forest vegetation of the Coal-measures. Only about four hundred species exist to-day as a remnant of its former display, although it still forms extensive forests. Gymnosperms are very diverse in habit. They are all woody forms, but they may be gigantic trees, trailing or straggling shrubs, or high-climbing vines. There are two prominent living groups of Gymnosperms.

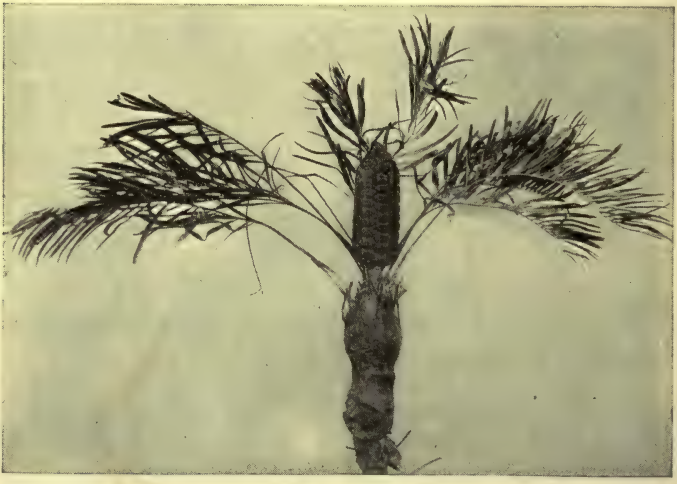

FIG. 200.—A cycad with tuberous or short thick stem.

Cycads are tropical forms with large fern-like leaves. The stem is either a columnar shaft crowned with a rosette of large compound leaves, with the general habit of tree-ferns and palms (Figs. 198 and 199); or they are like great tubers, crowned in the same way (Fig. 200). The tuberous stems are often more or less buried, as in our only cycad from the United States (Florida), illustrated in Fig. 200. In ancient times cycads were very abundant, but now they are represented by about eighty species scattered through the oriental and occidental tropics. They are especially interesting in their resemblances to ferns, and some of them might be mistaken for ferns did they not bear large seeds. In addition to their fern-like leaves, they have in the structure of the stem many fern characters; and they have coiled sperms with many cilia (Fig. 201), as do the ferns. They are very interesting to study; but it is easier to obtain the Gymnosperm characters from the other group, whose forms are far more familiar and easily obtained.

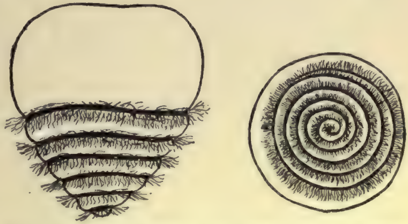

Fig. 201.—Two views of the sperm of a cycad, showing its spiral form and many cilia.

Conifers are the common Gymnosperms, often forming great forests in temperate regions. Some of the forms are widely distributed, as the pines; while some are now very much restricted, as the gigantic redwoods (*Sequoia*) of the Pacific slope. The habit of the body is quite characteristic, a central shaft extending to the very top (Fig. 42). In many cases, the branches spread horizontally, with diminishing length to the top, forming a conical outline, as in the firs. This habit gives the conifers an appearance very distinct from that of the other trees.

Another peculiar feature is the needle-leaf. These leaves have a small surface and very heavy protecting cells, being able to endure the cold of winter (Figs. 30 and 31). As there is no regular period for the fall of leaves, as in the deciduous trees, the trees are always clothed with them, and hence are called evergreens. A notable exception to the evergreen habit of conifers is that of the common larch or tamarack, which sheds its leaves every season.

The great body of the plant is highly organized for work, with its roots, stem, and leaves, and an elaborate vascular system connecting them all. The wood of the conifers is peculiar in its very regular grain, splitting easily; and its generally "soft" character is quite distinct from the so-called "hard woods." Throughout the body there are also numerous resin-ducts, whose contents give a peculiar aroma to the wood.

123. **Strobili.**—The cones borne by the conifers are well known, and suggest at once the strobili of certain Pteridophytes. There are two kinds of strobili, however, one being the conspicuous seed-bearing cones of common observation, the other much smaller and much less persistent cones (Fig. 202). In *Selaginella* (§ 118), it will be remembered, there are two kinds of sporangia in a single strobilus; but in conifers these two kinds of sporangia are in separate strobili or cones. In describing the two cones the pine may be used as an illustration.

The small cone (Fig. 202, *d*, and Fig. 203, *A*) is made up of sporophylls that look like small scales; and on the lower surface of each scale there are two sporangia (Fig. 203; *B* and *C*), each sporangium containing very numerous small spores (microspores). All of these structures received names long before their relations to the lower plants were known; but as these names are well known it is convenient to use them. The small spores were called *pollen grains* or simply *pollen;* the sporangia containing them were called *pollen sacs ;* and the sporophyll bearing the sporangia was called a *stamen.* The strobilus or cone, therefore, is a group of stamens; and to distinguish it from the other cone it may be called the *staminate cone.* It should be remembered, however, that all these structures are found also among Pteridophytes, though they are not called by these names.

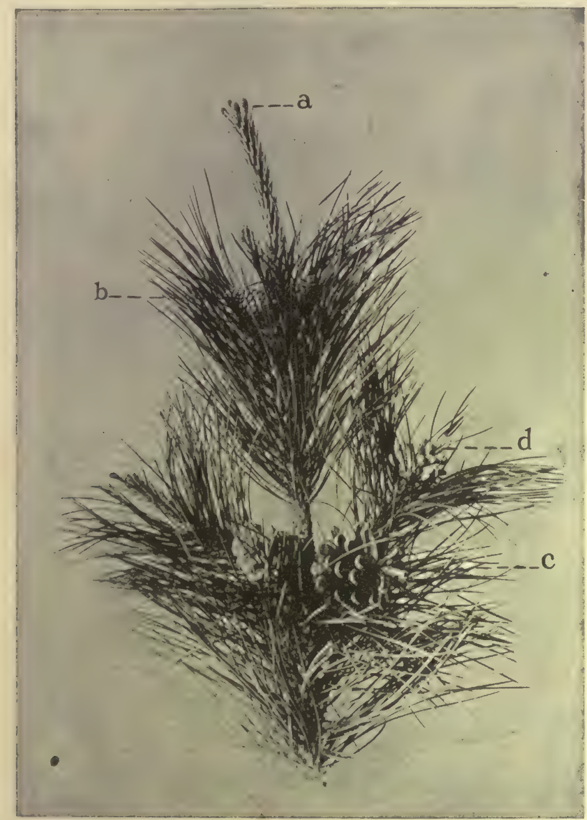

FIG. 202.—Tip of pine branch, showing carpellate cones of first year (*a*), second year (*b*), and third year (*c*); also a cluster of staminate cones (*d*).

The large cone of the pine is made up of sporophylls that become very thick and hard (Fig. 204, *A*), and that are packed closely together until they spread apart to let out the seeds (Fig. 202, *c*). On the upper side of each sporophyll, near its base, there are two sporangia (Fig. 204, *B* and *C*), in each one of which there is a single large spore (megaspore). So large is the spore that it looks like a conspicuous cavity in the center of the sporangium. These structures also bear old names that may be used. The sporangia were called *ovules ;* and the sporophyll bearing them was called a *carpel.* The large spore was regarded only as a cavity in the ovule. The cone, therefore, is a group of carpels; and to distinguish it from the staminate cone it may be called the *carpellate cone.*

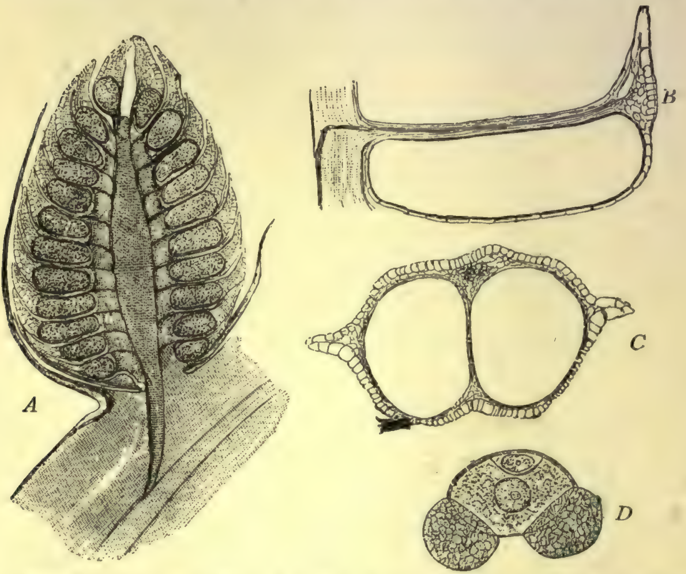

Fig. 203.—Staminate cone of pine: *A*, section of cone, showing sporophylls (stamens) bearing sporangia (pollen sacs); *B*, longitudinal section of stamen, through one pollen sac; *C*, cross-section of stamen, showing both pollen sacs; D, the winged pollen grain.—After Strasburger.

It is evident that the pine-tree, bearing these sporangia, is the sporophyte in the life-history; that is, it is the sexless generation. The sporophyte has now become so prominent that it seems to be the whole plant, and it is interesting to know what has become of the gametophytes with their sex-organs.

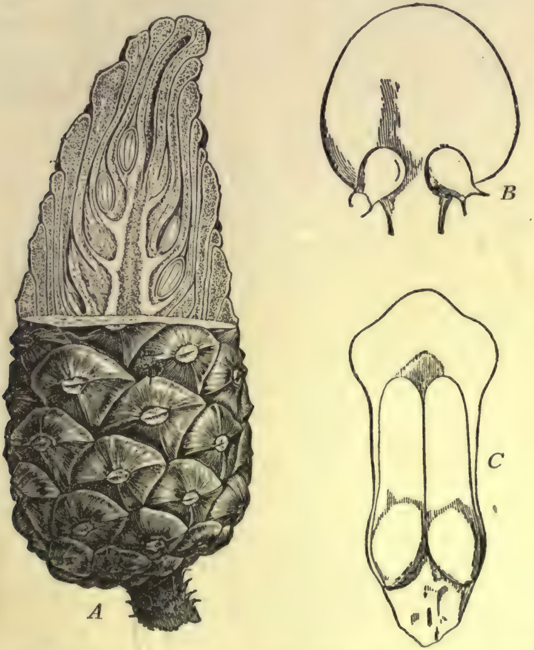

Fig. 204.—Carpellate cone of pine: *A*, cone partly sectioned; *B*, young carpel (sporophyll) with two ovules (sporangia); *C*, old carpel with mature seeds.—After Bessey.

124. **Gametophytes.**—As the pine is a heterosporous plant, there are male and female gametophytes. The small spores (pollen grains) germinate and produce very small male gametophytes. As in *Selaginella* (§ 118), only a few cells are formed, and these remain in the pollen grain (Fig.

203, *D*). Such a gametophyte has become so small that it can be seen only under the microscope. Among the cells formed, however, are two sperms. These sperms have no cilia, and hence it is evident that they do not reach the egg by swimming.

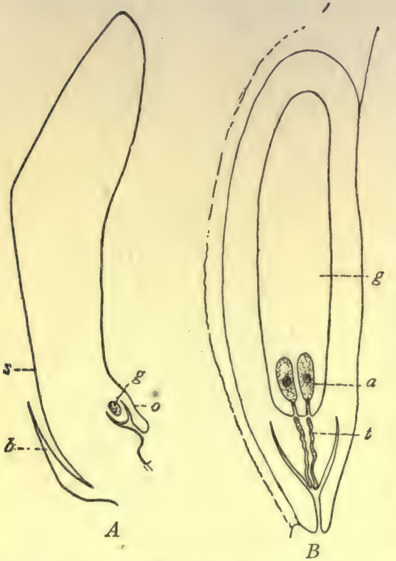

FIG. 205.—*A*, section showing the relative positions of bract (*b*), scale (*s*), and ovule (*o*) in a pine cone, the female gametophyte (*g*) being very young; *B*, enlarged section through the ovule a year later, showing the female gametophyte (*g*) bearing two archegonia (*a*) which are being reached by the penetrating pollen tubes (*t*).

The single large spore within the ovule (sporangium) is peculiar in never leaving it; that is, it is never shed, as are other spores. It produces a many-celled female gametophyte, just as does *Selaginella* (§ 118); and on this gametophyte archegonia are formed (Fig. 205). Since the large spore is not shed, the female gametophyte it produces lies embedded in the center of the ovule, like an internal parasite (Fig. 205, *g*).

It is evident now why the gametophytes of such plants are not ordinarily seen, for one is within the pollen grain and the other is within the ovule.

125. **Fertilization.**—Before fertilization can take place, the pollen grain, which develops the male gametophyte with its sperms, must be brought to the ovule, which contains the female gametophyte with its archegonia. The pollen grains (microspores) are formed in very great abundance, are dry and powdery, and are scattered far and wide by

the wind. In the pines and their allies the pollen grains are winged (Fig. 203, *D*), so they are well organized for wind distribution. This transfer of pollen from the staminate cone to the carpellate cone is called *pollination*, and the agent of transfer is the wind. So abundant is the pollen of conifers that it sometimes falls like a yellow shower, and the occasionally reported "showers of sulphur" are really showers of pollen from some forest of conifers. Some pollen must reach the ovules, and to insure this it must fall like rain. To aid in catching the falling pollen the scale-like carpels of the cone spread apart; and the pollen grains sliding down their sloping surfaces collect in a little drift at the bottom of each carpel, where the ovules are found.

In this position each of the most favorably placed pollen grains begins to put forth a tube (*pollen tube*). This tube, containing the two sperms in its tip, grows through the ovule, and reaches the archegonia (Fig. 205, *t*). Then the sperms are discharged, and when they reach the egg fusion takes place and fertilization is accomplished.

126. **Embryo.**—The oöspore that has been formed within the archegonium at once germinates and begins to form the young plantlet (*embryo*), which of course is still within the ovule. This embryo continues to grow, feeding upon the female gametophyte that surrounds it. It is evident that this embryo is the young sporophyte of the next generation.

127. **Seed.**—While the embryo is developing, some important changes are taking place in the ovule outside of the female gametophyte. The most notable change is the formation of a hard, bony covering, which hermetically seals the structures within, so that further development is checked. In this way the ovule (sporangium) has been transformed into what is called a *seed*, the distinguishing structure of seed-plants.

If a pine seed is cut open, the embryo (young sporophyte) may be seen embedded in the center (Fig. 206); around it is packed nutritive tissue (often called *endosperm*), which is the female gametophyte; and outside of that there is found the bony seed-coat (*testa*). In this condition of suspended animation the embryo may continue for a long time, certainly until the next season, perhaps for many seasons. When the seed comes into favorable conditions and "awakens," the embryo escapes and grows into the pine-tree. This awakening of the seed is usually called its "germination," but it must not be confused with the germination of spores and oöspores. The "germination" of the seed is merely the resumption of growth by the embryo and its escape from the seed. In seed-plants, therefore, there are two distinct periods in the growth of the sporophyte, the period within the seed (when it is called an embryo), and the period outside of the seed; and these two periods may be separated from one another by a long period of time. For an account of seed germination see Chapter V.

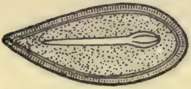
FIG. 206.—Section of a pine seed, showing embryo (young sporophyte) embedded in endosperm (female gametophyte), which is invested by the hard testa.

128. **Timber from Conifers.**—The conifers are the most important source of timber in the United States, yielding at least three-fourths of our supply. They are usually called "soft woods" in distinction from the so-called "hard woods," such as oak; but there are soft and hard woods in both groups. The United States is notable for its variety of pines, broadly grouped into the soft white pine and the hard yellow pines. Our principal supplies come from the white pine forests about the Great Lakes and the yellow pine forests of the Southern States; but the forests of the former region have been cut over so ruthlessly for so long a time that the supply of white pine is diminishing. A few years ago the white pine furnished nearly one-third of all the timber produced by the United States. It is very

important to learn how to obtain white pine with the least possible waste, for the usual methods will soon destroy all of our supply.

The pine forests of the South, yielding in increasing amount the very valuable timber of the hard wood yellow pines, are very extensive. Chief among these yellow pines is the Georgia pine, being the principal species over an area fifty to one hundred and fifty miles wide and extending along the coast region from North Carolina to eastern Texas. This great Southern pine region is producing more and more timber as the supply from the Northern white pine is diminishing.

The coniferous forests mentioned above belong to the general Atlantic region, which extends from the Atlantic Coast to the Mississippi Valley; but there is a Pacific region extending from the Rocky Mountains to the Pacific Coast, all of whose immense forests are conifers. These Western forests are mainly in the mountains, and have been most wastefully treated in cutting for timber, clearing, and permitting the ravages of fire. Two famous coniferous trees of California are the redwood and the big tree. The former yields a very valuable lumber, and the latter is the largest American tree. The big trees are found in scattered groves along the western slopes of the Sierra Nevada, a number of which are carefully preserved. The height of the standing trees reaches 325 feet, but a fallen tree is estimated to have been over 400 feet high. The diameter of the trunk near the ground sometimes reaches 30 to 35 feet.

129. **Resin and turpentine.**—The conifers in general contain resins, and from certain pines the common resin (or rosin) and turpentine of commerce are obtained. Usually incisions are made into the wood of the trees and a resinous liquid exudes, which is crude turpentine. This liquid is distilled, the oil or spirit of turpentine coming off and being collected, and the resin remaining behind in the still.

CHAPTER XIII

ANGIOSPERMS

130. **General characters.**—This is the greatest group of plants, both in numbers and importance. It comprises more than 100,000 species, and forms the most conspicuous part of the vegetation of the earth. It includes herbs, shrubs, and trees in profusion, and represents the plant kingdom at its highest development. There is the greatest possible variety in habit, size, and duration: from minute floating forms to gigantic trees; erect, prostrate, and climbing; aquatic, terrestrial, epiphytic; from a few days to centuries in duration.

The most striking feature of the Angiosperms to the ordinary observer is that the majority of them produce what every one recognizes as *flowers;* and hence they are often spoken of as flowering plants. The production of flowers, however, is not the real distinction of the group, but it is a very prominent feature and suggests the group to most people better than any other character.

The general structure of the roots, stems, and leaves of this great group was presented in Chapters II, III, and IV, so that there remain for consideration the flower and the structures associated with it.

131. **The flower.**—It is impossible and unnecessary to define a flower, but it is not at all difficult to recognize ordinary flowers. They are objects of such common experience that no one is at a loss to understand what is meant when the word is used. The parts of a flower may

be understood best by selecting for description some simple flower that has all the floral members, as, for example, the buttercup.

In such a flower there are four distinct sets of members (Fig. 207). The outermost set has the color and the form of small leaves, each member being called a *sepal*, and the whole set the *calyx*. The next inner set is usually the showy one, with members of relatively large size, delicate texture, and bright color, each member being called a *petal*, and the whole set the *corolla*. The set just within the corolla comprises the *stamens*, which produce the pollen. The central set is made up of the *carpels*, which contain the ovules that are to become seeds.

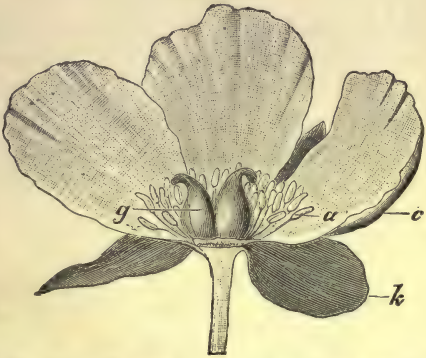

Fig. 207.—Flower of peony: *k*, sepals; *c*, petals; *a*, stamens; *g*, carpels.—After Strasburger.

The endless variations of these sepals, petals, stamens, and carpels, make the differences among flowers, and it is astonishing in how many ways the variations of four parts can be combined. It will be impossible to describe even the conspicuous variations and combinations, but certain general tendencies may be pointed out. It is important for the student to examine as many of the common flowers of his neighborhood as possible, and to discover how they differ from one another; for it is these floral differences that are most used in classifying Angiosperms.

132. **Sepals.**—While the sepals generally look like small green leaves, this is by no means always true. Sometimes they are as brightly colored as petals; and often they appear

united, so that the calyx is a little cup or tube (Fig. 208). In any case, the calyx is useful in the bud condition of the flower in protecting the more delicate parts within. Sometimes the sepals and the petals look so much alike that they are spoken of together as the *perianth*, as in the common lily (Fig. 274). Occasionally there is only one floral set outside the stamens; and it has become the custom to call it a calyx, assuming that the corolla is lacking. In still other cases, there are no floral members outside the stamens; and then the flower is said to be *naked.*

133. **Petals.**—The attractiveness of flowers usually depends upon their petals, and hence their differences in color and form are things of common experience. In many flowers the petals are entirely distinct from one another and can be pulled off separately. In many other flowers,

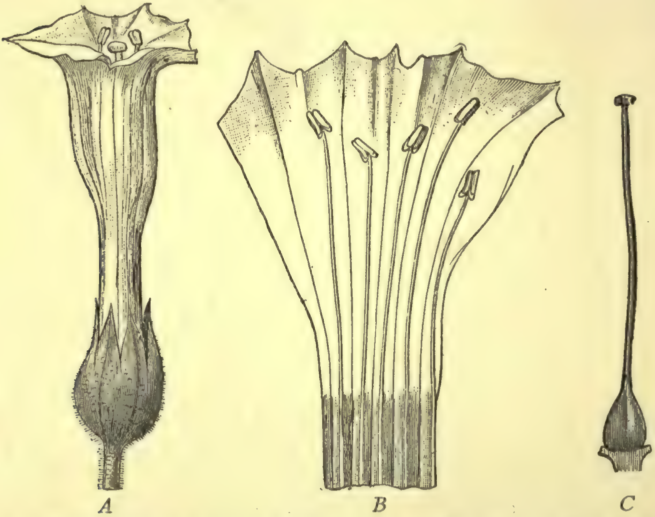

FIG. 208.—Flower of tobacco: *A*, sympetalous corolla, calyx urn-like; *B*, tube of corolla cut open and showing attachment of stamens; *C*, the pistil, showing ovary, style, and stigma.—After STRASBURGER.

however, the petals appear to be united so that the corolla becomes a cup, urn, tube, funnel, or the like (Figs. 208 and 209). This condition of the corolla is so constant in the highest group of Angiosperms that the group is called the *Sympetalæ,* because the corollas are *sympetalous* (petals together).

In many flowers with sympetalous corollas there is an irregular development, so that the mouth of the tube, instead of being regular, is divided into two unequal lips, as in the mints and many others (Fig. 209, *C—E*). Such flowers are said to be *bilabiate* (two-lipped), and on this account the Mint Family is named *Labiatæ.* Such corollas may have further irregularities in the form of more or less conspicuous projections at the base called *spurs* (Fig. 209, *E*). It must not be supposed that irregular growths are found only in connection with sympetalous corollas; for the sweet pea represents a great family in which the petals are all separate, and yet they are very much unlike; and in the violet, whose petals are distinct, one of them has a conspicuous spur.

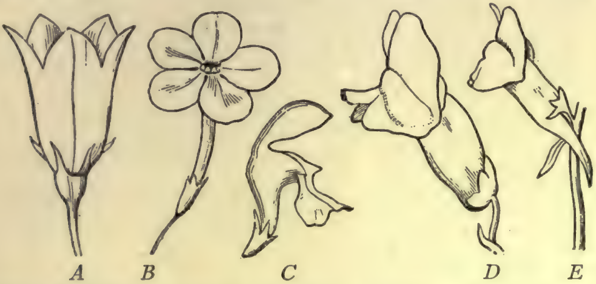

Fig. 209.—Sympetalous flowers: *A*, bluebell; *B*, phlox; *C*, dead-nettle; *D*, snapdragon; *E*, toadflax.—After Gray.

The corolla is useful in protecting the young stamens and carpels, but it is also associated with the visits of insects, a subject which will be spoken of later.

134. **Stamens.**—From our study of Gymnosperms (§ 123), the stamen of the Angiosperm flower is recognized as a sporophyll bearing sporangia, which produce the small spores (microspores) called pollen grains. The stamen of Angiosperms, however, has two very distinct regions. There is a stalk, which is usually slender and long, called the *filament;* and at the top of this there is the knob-like sporangium-bearing region called the *anther* (Fig. 210).

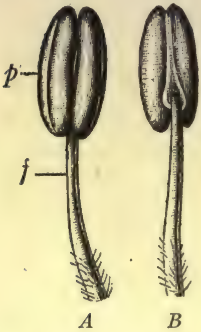

FIG. 210.—Front (*A*) and back (*B*) views of a stamen, showing filament (*f*) and anther (*p*), the latter including two pollen sacs.—After SCHIMPER.

A cross-section of a very young anther usually shows that it contains four sporangia, that is, four regions in which spores are formed (Fig. 211). As the anther matures, the two regions on each side run together, so

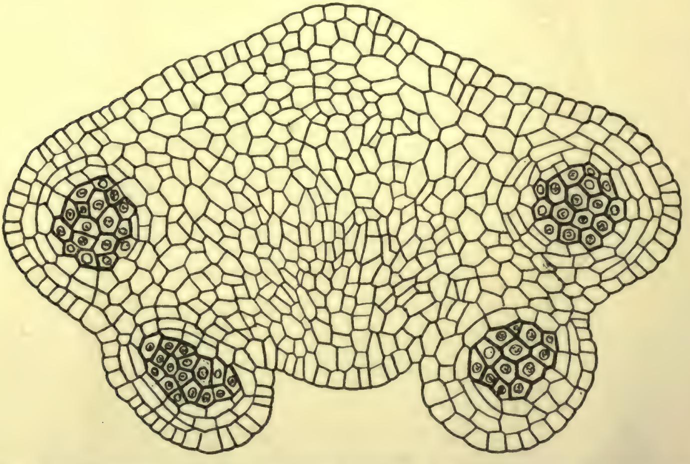

FIG. 211.—Cross-section of a very young anther of a lily, showing the four developing sporangia.

that the anther comes to contain only two spore chambers (Fig. 212). These two spore chambers are plainly

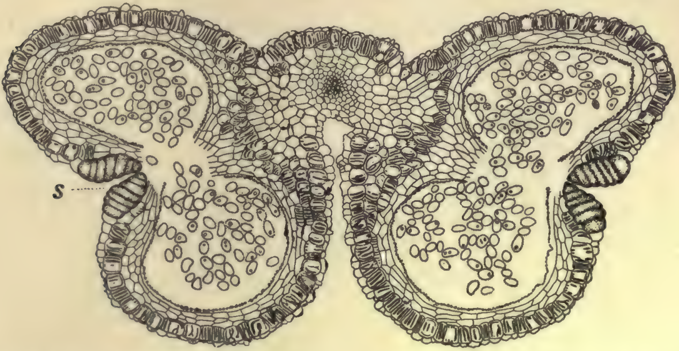

FIG. 212.—Cross-section of a mature anther of a lily, much larger than that shown in Fig. 211, showing the two chambers formed by the four sporangia, and also the region of opening (*s*).

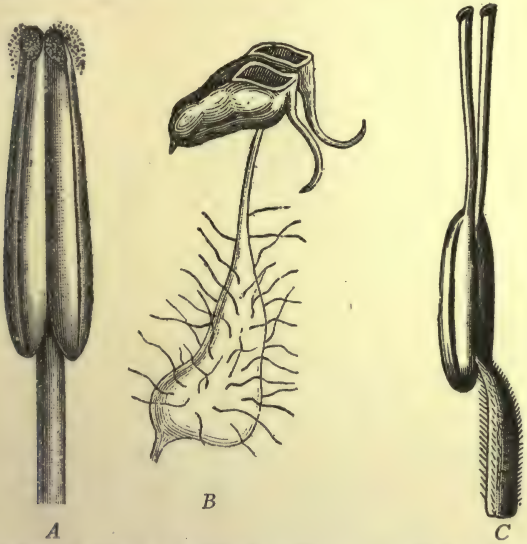

FIG. 213.—Anthers opening by terminal pores: *A*, *Solanum;* *B*, *Arbutus;* *C* *Vaccinium.*—*A* and *B*, after ENGLER and PRANTL; *C*, after KERNER

visible from the outside, looking like two sacs, called *pollen sacs.* Ordinarily, therefore, the Angiosperm stamen is said to have two pollen sacs.

In most cases the pollen sacs must open so that the pollen may escape, and the method of opening differs in different flowers. By far the most common way is for each pollen sac to split open lengthwise, and this line of splitting is usually plainly seen on the surface of the unopened sac (Fig. 210, *A*). In some cases, however, each pollen sac opens at the top, either by a short slit or by a pore-like opening (Fig. 213, *A* and *B*); and in some cases, as among the heaths, this pore-like opening may be extended into a more or less prominent tube (Fig. 213, *C*). There are still other special methods of opening pollen sacs, but they are comparatively rare.

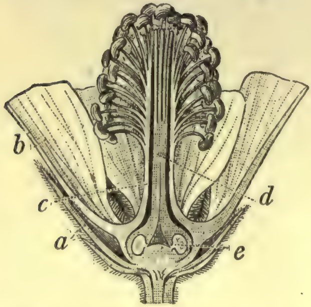

FIG. 214.—Section of the flower of an *Althæa*, showing sepals (*a*), petals (*b*), tube of stamens (*c*) enclosing style (*d*), and ovules (*e*).—After BERG and SCHMIDT.

In sympetalous corollas it is most common for the stamens to appear fastened to the tube of the corolla (Fig. 208, *B*), and this condition is usually described as "stamens inserted on the tube of the corolla." Stamens may also appear united, forming a tube, as in mallows (hollyhock, etc.) (Fig. 214); or they may be in two sets, as in the sweet pea, in which nine of the stamens appear united and the tenth one is free (Figs. 241 and 283).

135. **Carpels.**—It has been noted that carpels are the sporophylls that bear the peculiar sporangia called ovules (§ 123). There is a striking difference, however, between the carpels of Gymnosperms and Angiosperms, a difference that gives names to the two groups. In Gymnosperms the

ovules are exposed on the surface of the carpel, while in the Angiosperms they are enclosed by the carpel as in a closed vessel. Gymnosperm means "seed naked," and Angiosperm means "seed in a vessel"; hence the names of the groups refer to this difference in the carpels.

The carpel of an Angiosperm flower has the general shape of a flask (Figs. 207 and 215, *A*). The bulbous bottom in which the ovules are enclosed is called the *ovary;* the neck of the flask, which may be short or long, is called the *style;* and upon the style, either on its top, which is often knob-like, or along its side, there is a specially prepared surface to receive the pollen, known as the *stigma.* This stigmatic surface, when ready to receive the pollen, is sticky; the style, unlike the neck of a flask, is usually solid; so that the ovary is the only part of the carpel that is hollow. The ovules in an ovary vary in number from a single one to a great number, and they are borne in a variety of positions on the inner wall of the ovary.

In many flowers the carpels remain separate (Figs. 207 and 215, *A*), as in the buttercups; but it is very common for all the carpels of a flower to unite in the formation of a single structure, whose general outline is that of a single carpel. That is, it has a single ovary and may have a single style (Figs. 208, *C*, and 215, *C*). It is convenient to have a word to apply to this ovule-containing structure, whether it consists of one carpel or of several organized together,

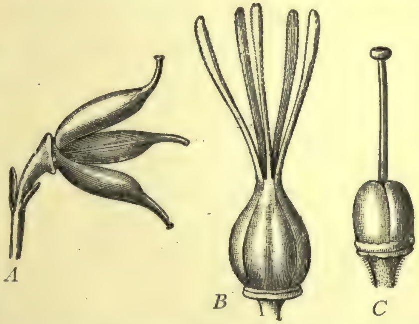

FIG. 215.—*A*, simple pistils (each one a single carpel); *B* and *C*, compound pistils (each one composed of several carpels).—After BERG and SCHMIDT.

and such a word is *pistil*. A pistil, therefore, is any organization of carpels that appears as a single organ with one ovary. A pistil composed of one carpel is called a *simple pistil* (Figs. 207 and 215, *A*), and one composed of more than one carpel is a *compound pistil* (Figs. 208, *C*, and 215, *C*). When a flower has one pistil, it is necessary to discover whether it is a simple or a compound pistil, and if it is the latter to determine the number of carpels that enter into its structure. Sometimes the styles are separate (Fig. 215, *B*), or the single style is cleft more or less deeply; and in either case the answers to both questions are very apparent. But often the style is single throughout and does not indicate the number of carpels. In that case the ovary must be cross-sectioned, and if the section reveals more than one ovule chamber the compound character and the number of carpels are usually apparent (Fig. 216, *B*). Sometimes, however, a compound ovary may have only one ovule chamber, and in this case the number of carpels may be indicated by the number of rows of ovules on the wall (Fig. 216, *A*).

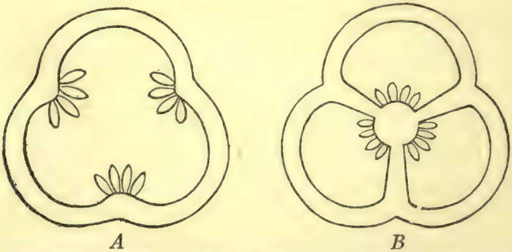

FIG. 216.—Diagrammatic cross-section of compound ovaries: *A*, a one-chambered ovule composed of three carpels; *B*, a three-chambered ovule.—After SCHIMPER.

It is necessary to know something about the structure of the Angiosperm ovule (Fig. 217). That it is a sporangium containing one large spore (megaspore) that is never shed, was pointed out in connection with the Gymnosperms

(§ 123). On the outside of this ovule one or two special coverings are developed, called *integuments*. These integuments grow up about the ovule, but do not completely cover it at the top, leaving a little opening called the *micropyle* (little gate). This micropyle is a very important feature in the ovule and also later in the seed. The body of the ovule within the integuments is called the *nucellus*, and within the nucellus the large spore (megaspore) lies embedded (Fig. 217). The three types of ovule are shown in Fig. 217: the erect ovule (*A*), the curved ovule (*B*), and the inverted ovule (*C*), the last being the most common.

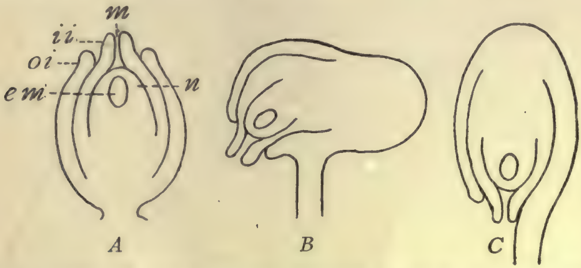

FIG. 217.—Diagrammatic longitudinal sections of ovules, showing outer (*oi*) and inner (*ii*) integuments, micropyle (*m*), nucellus (*n*), and megaspore (*em*), the last often called embryo sac: *A*, erect ovule; *B*, curved ovule; *C*, inverted ovule.

136. **Floral numbers.**—In many flowers there is no regularity in the number of members in each set. For example, in the water-lily petals and stamens occur in indefinite numbers; and in the buttercup the same is true of stamens and carpels. In most flowers, however, definite numbers appear either in some of the sets or in all of them. When these definite numbers are present, they are prevailingly either *three* or *five;* that is, there are either three or five sepals, petals, stamens, and carpels; although it is very common to have two sets of stamens, in which case they number six or ten. These numbers appear so constantly in great groups that the two grand divisions of Angio-

sperms, called *Monocotyledons* and *Dicotyledons*, are characterized by them, the former having the parts of the flower in threes, the latter in fives. This does not mean that all flowers of these two divisions have one or the other number, but that these are the prevailing numbers in case there is a definite number at all. Not a few Dicotyledons have flowers with the parts in threes, and a still larger number have them in fours.

137. **Staminate and pistillate flowers.**—In many cases stamens and pistils are not found together in the same flower. In such cases there are *staminate flowers*, that is, those without pistils; and *pistillate flowers*, that is, those without stamens. These two kinds of flowers may be borne upon the same plant, which is then said to be *monœcious* (one household); or upon different plants, which are then said to be *diœcious* (two households). These terms are applied indifferently to the plants or to the flowers, either the plants or the flowers being spoken of as monœcious or diœcious. In a diœcious plant, therefore, one can speak of staminate and pistillate plants, one bearing fruit and seed and the other not. Many of our common trees, as willows and poplars, are diœcious; and many more, as oaks, walnuts, and hickories, are monœcious.

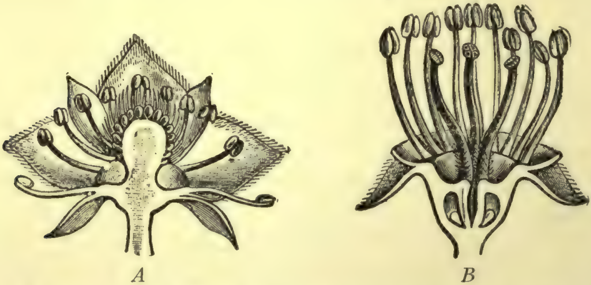

FIG. 218.—Hypogynous flower of *Potentilla* (*A*), and epigynous flower of apple (*B*).—After ENGLER and PRANTL.

138. Hypogynous and epigynous flowers.—In many flowers the sepals, petals, and stamens are seen to be attached under the ovary, that is, the ovary appears within the flower (Fig. 218, *A*). Such a flower is said to be

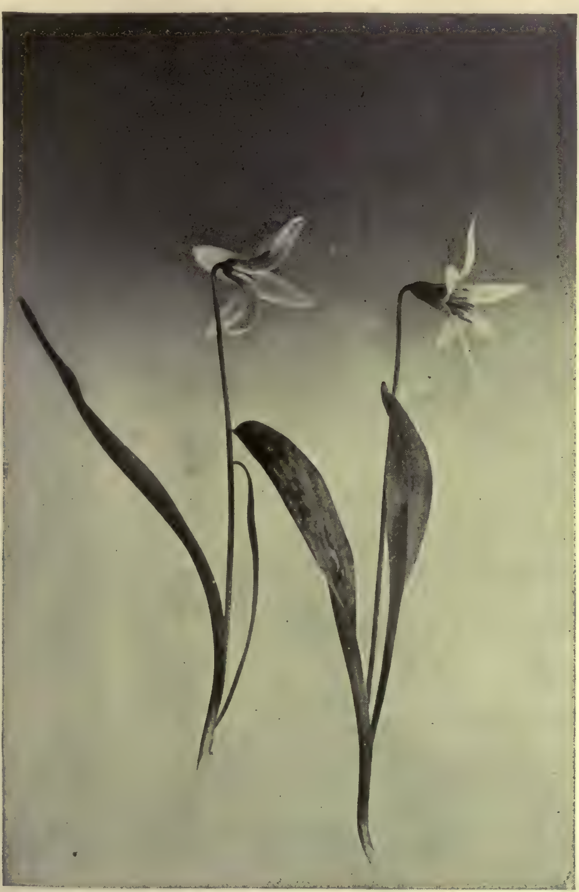

FIG. 219.—Dogtooth violet, with hypogynous flowers (Lily Family).

hypogynous (under the pistil), and in descriptions of flowers this condition is often called "ovary superior." In many other flowers, on the other hand, the sepals, petals, and stamens all seem to be attached to the top of the ovary; that is, the ovary appears beneath the flower (Fig. 218, *B*). Such a flower is called *epigynous* (upon the pistil), or described often as "ovary inferior." This is a very important distinction, because it characterizes great groups of plants; for example, all members of the Lily Family are hypogynous (Fig. 219), and all members of the Amaryllis and Iris Families are epigynous (Fig. 220). It is also interesting to note that all the plants of highest rank in their respective lines have epigynous flowers.

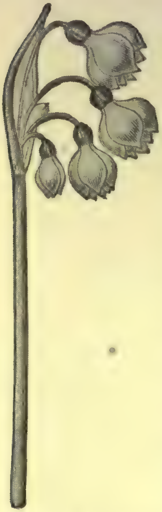

FIG. 220.—Snowflake, with epigynous flowers (Amaryllis Family). — After STRASBURGER.

139. **Flower clusters.**—In many cases a single flower terminates the stem, or flowers may occur in the axils of ordinary leaves. But more frequently flowers occur in definite clusters, which are characteristic and help to distinguish plants. It is unnecessary to enumerate all the forms of flower clusters and their names, but some of the more important may be noted.

One of the most common kinds of clusters is that in which the flowers arise along an axis, resulting in a more or less elongated and often drooping cluster. This is called a *raceme*, and the flowers may be loosely or densely arranged (Fig. 221). If in such a cluster the flowers have no stalks, and rest directly on the axis, the cluster is called a *spike*, as in the common plantain (Fig. 222). If the cluster is flat-topped, with the flower-stalks rising and spreading like the braces of an umbrella, it is an *umbel*, as in cherry (Fig. 223), wild parsnip, carrot, etc. (Fig. 224).

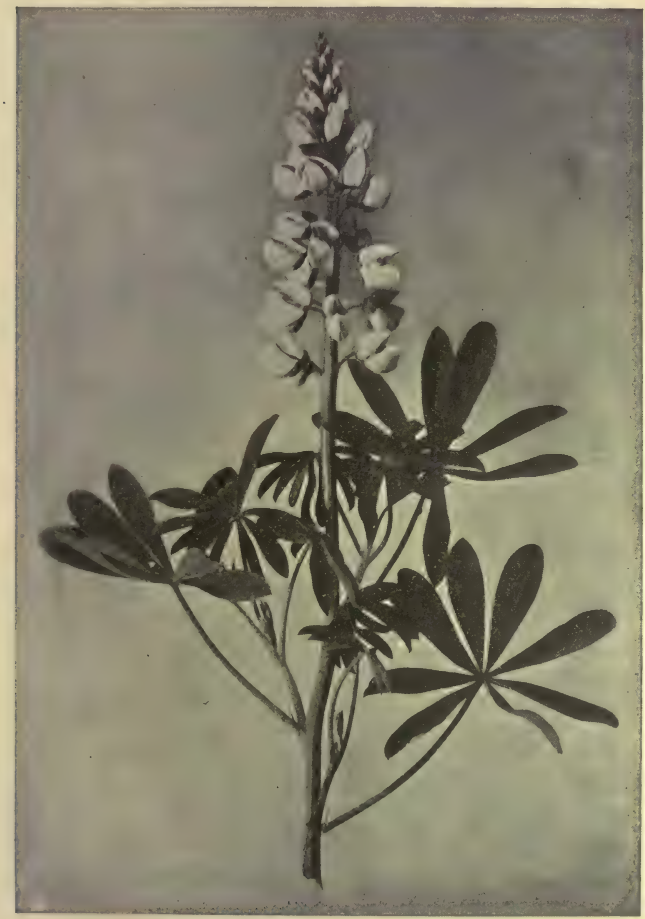

FIG. 221.—Raceme of lupine.

If one can imagine the flowers of an umbel without any stalks, so that they would be packed closely together at the top of the main axis, the cluster is called a *head*, the most notable illustrations being such plants as the sunflower or dandelion, whose so-called "flowers" are compact clusters or heads of numerous small flowers (Figs. 298 and 299).

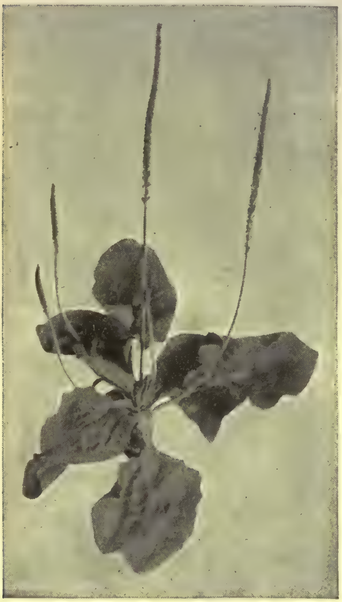

FIG. 222.—Spikes of plantain

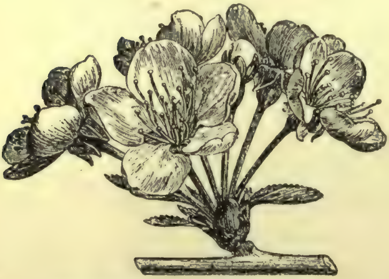

FIG. 223.—Umbel of cherry.—After DUCHARTRE.

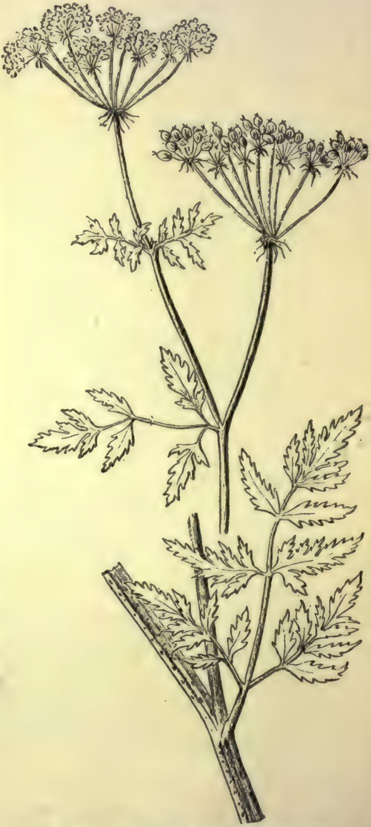

FIG. 224.—Umbel of hemlock.—After SCHIMPER.

140. The gametophytes.—The gametophytes of Angiosperms are even more reduced than those of Gymnosperms (§ 124). In order to see them, special preparations for the microscope are necessary, but with the help of illustrations some idea of them may be obtained. By the pollen grain (microspore) three cells are formed, and two of them are male cells or sperms; these three cells represent the male gametophyte (Fig. 225). Within the large spore (megaspore), which is retained in the ovule, seven cells usually appear; and one of these is an egg, no archegonium to contain it being formed. These seven cells represent the female gametophyte before fertilization (Fig. 226).

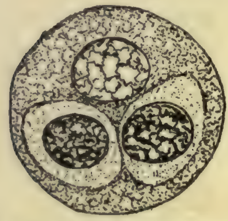

Fig. 225.—Pollen grain containing a three-celled male gametophyte; one cell represented by its nucleus, the two other cells being male cells.

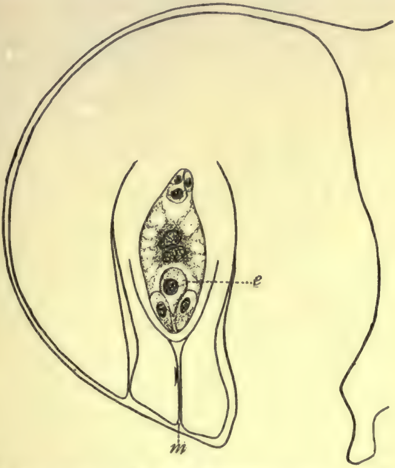

Fig. 226.—The female gametophyte of a lily before fertilization, within the old megaspore wall eight cells or their nuclei appearing, one of which is an egg (*e*); the pollen tube enters through the micropyle (*m*).

The sperms produced by the pollen must reach the egg within the ovule. The stamens that produce the pollen may be in the same flower as the pistil that contains the ovules with their eggs, or they may be in another flower on the same plant, or they may be borne by an entirely different plant. In any event, the first thing done is to transfer the pollen to the pistil. This transfer, that is, pollination (§ 125), is effected in many Angiosperms by insects, and how this is brought about will be described later.

The pollen grains that reach the stigma, the specially prepared surface for receiving them, begin to put out pollen tubes. These tubes grow through the stigma and enter the style; grow down the style and enter the cavity of the ovary; reach the ovules and enter their micropyles; and finally penetrate the ovule to the egg (Fig. 227). Throughout this progress of the tube the male cells are in its tip, and when the egg is reached they are discharged from the tube and one of them fuses with the egg. This is the act of fertilization, and through it the egg becomes an oöspore.

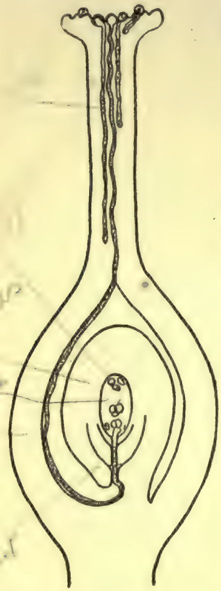

FIG. 227.—Diagrammatic representation of pollen tubes penetrating the style; one of them entering the ovary cavity, passing down its wall, and reaching the female gametophyte by way of the micropyle.

An important difference between Gymnosperms and Angiosperms should be noted here. In Gymnosperms the pollen reaches the ovules, for they are exposed; but in Angiosperms the pollen reaches only the surface (stigma) of the pistil that encloses the ovules.

141. **Embryo.**—The oöspore, lying in the midst of the ovule, at once begins to germinate, and forms a young plant or *embryo*. While the embryo is forming, the ovule develops a hard coat outside, and a seed is the result (Fig. 228). The general structure of the seed and how the young plant escapes from the seed have been described in Chapter V.

The two great divisions of Angiosperms are named from the peculiar character of their embryos. In one division the root is developed at one end of the embryo and the single cotyledon at the other end, the stem coming out on one side. In the other division the root is developed at one end of the embryo and the stem at the other end, two cotyledons coming out on opposite sides just behind the stem tip. Therefore, the first division is called *Monocotyledons* (one cotyledon), and the second is called *Dicotyledons* (two cotyledons). There are many other differences between Monocotyledons and Dicotyledons, but this difference between the embryos has been selected to form the names.

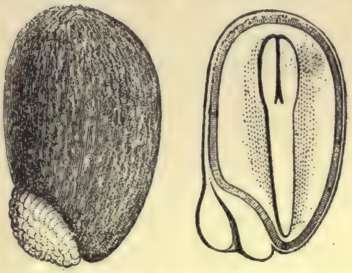

FIG. 228.—Seed of violet, one figure showing the hard testa, the other the embryo (young sporophyte) that has developed from the oöspore.—After BAILLON.

The embryos of Angiosperms differ much as to the completeness of their development within the seed. In some plants the embryo is merely a mass of cells, without any organization of root, stem, or leaf. In many plants, on the other hand, the embryo becomes highly developed, showing all the principal organs and the plumule containing several well-organized young leaves (Chapter V).

142. **Seed.**—The seed is evidently an ovule (sporangium) containing a female gametophyte which has developed a new sporophyte (embryo). This complex structure is invested by the hard seed-coat, and is a protected resting condition of the plant.

The seed-coat (*testa*) in Angiosperms is exceedingly variable in structure and appearance. Sometimes it is smooth and glistening, sometimes pitted, sometimes rough with warts or ridges. In many cases prominent appendages are produced, as wings, tufts of hairs, etc., which assist in seed dispersal, a subject which will be considered later.

143. **Fruit.**—Accompanying the changes in ovules involved in the formation of seeds, there are other changes in the surrounding parts resulting in the formation of a *fruit*. These changes may involve only the ovary wall, or they may include also other adjacent structures; but the whole resulting structure, whatever it may include, is called a fruit. The fruits of Angiosperms are so exceedingly diverse that it will be possible to give only a very general outline of the various kinds.

For convenience, those fruits will be considered first that represent only the enlarged and modified ovary. Such fruits may be placed in two groups: those that ripen dry and those that ripen fleshy.

(1) DRY FRUITS.—In these the ovary wall not only changes, but also usually becomes hard or parchment-like. Dry fruits may open to discharge their seeds, but often when there is only one seed in an ovary the fruit does not open. Thus there are two groups of dry fruits: the dehiscent (opening) and the indehiscent (unopening).

a. Dehiscent fruits.—Dry fruits that open are in general called *pods*, and usually they open by splitting, as the pods of peas and beans. The great family to which peas and beans belong is named for its pod, being

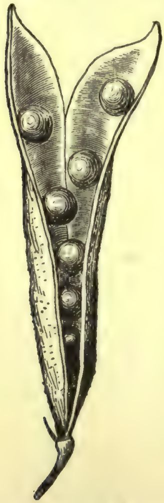

FIG. 229.—Pod of sweet pea dehiscing.—After GRAY.

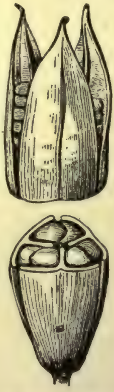

FIG. 230.—Capsule of iris dehiscing.—After GRAY.

called the *Leguminosæ*, a *legume* being a special kind of pod (Fig. 229). When a pod is derived from a compound pistil, forming a fruit of several chambers, it is more commonly called a *capsule;* and capsules differ from one another in the way the chambers are opened (Fig. 230).

b. *Indehiscent fruits.*—The most common form of dry fruits that do not open is that in which the modified ovary wall invests the solitary seed so closely that the fruit looks like a seed, and is commonly called a seed. The *grain* of cereals is such a seed-like fruit, as is also the *akene* of sun-flowers, dandelions, etc. (Fig. 231).

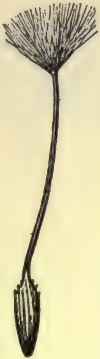

FIG. 231.—Akene of dandelion, which tapers above into a long beak bearing a tuft of hairs.—After GRAY.

(2) FLESHY FRUITS.—In some cases the whole ovary becomes a thin-skinned pulpy mass in which the seeds are embedded, as the grape, currant, gooseberry, tomato, etc., such a fruit being a *berry*. Modifications of the berry are seen in such fruits as the orange and the lemon, in which the skin is leathery; and in such fruits as melons and pumpkins, which become covered with a hard rind. Very distinct from these are the *stone-fruits* (*drupes*), as peach, plum, cherry, etc., in which the ovary wall ripens in two layers, the inner one being very hard, forming the "stone," and the outer one being pulpy (Fig. 232). In general, fleshy fruits do not open; but the banana is a peculiar fleshy fruit that dehisces.

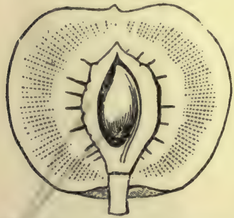

FIG. 232.—Section of peach, showing pulp and stone formed from ovary wall and enclosing the seed (kernel).—After GRAY.

All of the fruits mentioned above include only a modified ovary wall with its contents, but many of the most common fruits do not answer to this description. A few of the most conspicuous of these will serve as illustrations.

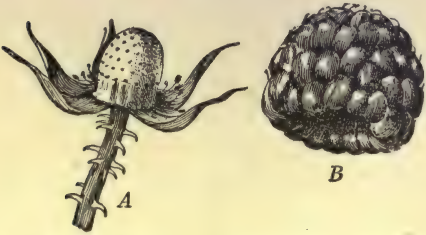

FIG. 233.—Raspberry: *A*, flower-stalk, with calyx, old stamens, and prominent receptacle, from which the berry (a cluster of small stone-fruits) has been removed (*B*).—After BAILEY.

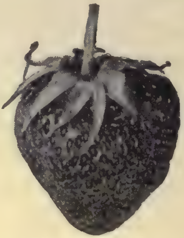

FIG. 234.—Strawberry: an enlarged pulpy receptacle in which numerous small akenes are embedded.

A number of the best-known fruits have been named "berries" that are not berries as described above. For example, a raspberry is a mass of very small stone-fruits that slips from the enlarged top of the flower axis (*recep-*

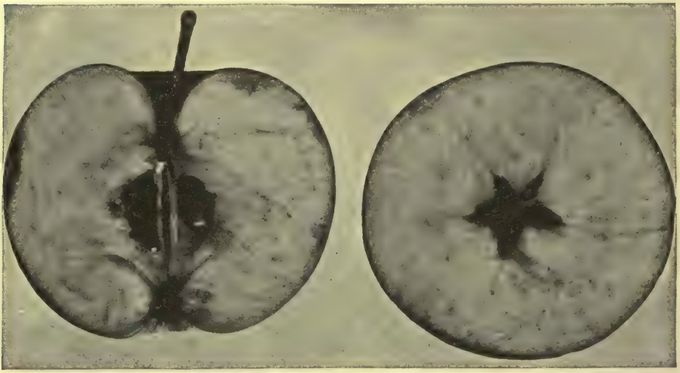

FIG. 235.—Longitudinal and transverse sections of apple, showing the five-celled ovary (core) embedded in the fleshy cup of the flower.

tacle) like a cap (Fig. 233). A strawberry is a very much enlarged and fleshy receptacle, in the surface of which minute akenes are imbedded (Fig. 234). A blackberry is not only a cylindrical mass of small stone-fruits, but also includes the fleshy receptacle.

In such fruits as apples, pears, and quinces, the fleshy part is the modified cup-like base of the flower surrounding the ovary, which with its contained seeds is represented by the core (Fig. 235). An extreme case is the pineapple, in which a whole flower-cluster has become an enlarged fleshy mass, including axis and bracts (Fig. 236).

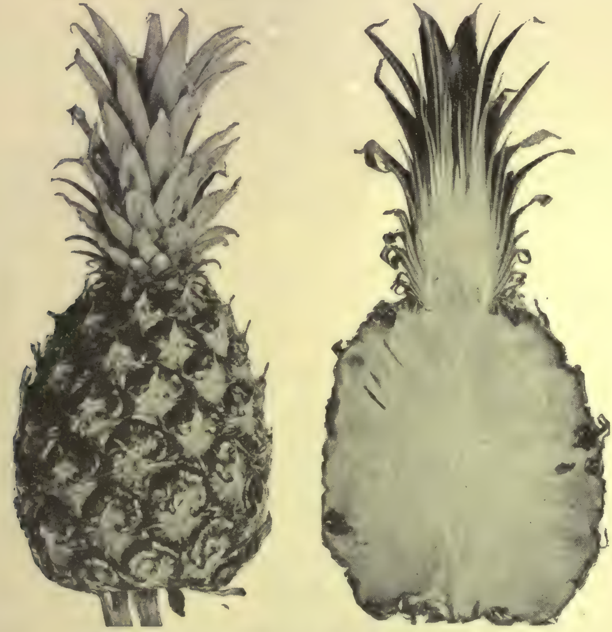

Fig. 236.—Pineapple in surface view and section.

CHAPTER XIV

FLOWERS AND INSECTS

144. Pollination.—Among Gymnosperms the pollen is transferred by the wind, and this is true also of many Angiosperms. But the prevailing method of pollination among Angiosperms is the use of insects as the agents of transfer. This mutually helpful relation between flowers and insects is a very remarkable one, and in some cases it has become so intimate that they cannot exist without each other. Flowers are modified in many ways in relation to insect visits, and insects are variously adapted to flowers.

The pollen may be transferred to the stigma of its own flower (*self-pollination*), or to the stigma of some other flower of the same kind (*cross-pollination*). In the latter case the two flowers concerned may be upon the same plant or upon different plants, which may be quite distant from one another. Since flowers are very commonly arranged to secure cross-pollination, it must be more advantageous in general than self-pollination.

The advantage of this relation to the insect is to secure food. This the flower provides in the form of either nectar or pollen; and insects visiting flowers may be grouped as nectar-feeders, represented by moths and butterflies, and pollen-feeders, represented by the numerous bees and wasps. The presence of these supplies of food in the flower is made known to the insect by the display of color, by odor, or by form. It should be said that the attraction of insects to flowers by color has been doubted, since it is claimed that some of the common flower-visiting insects are color-blind, but remarkably keen of scent. However this may be for some insects, it seems to be sufficiently established that many insects recognize their feeding ground by the display of color.

It is evident that all insects attracted by nectar or pollen are not suitable for the work of pollination. For instance, ordinary ants are fond of such food, but as they walk from plant to plant any pollen dusted upon them is almost sure to be brushed off on the way and lost. The most favorable insect is the flying one, which can pass from flower to flower through the air. It will be seen, therefore, that the flower not only must secure the visits of suitable insects, but also must guard against the depredations of unsuitable ones.

145. **Self-pollination.**—It is evident that in many cases self-pollination is likely to occur. In some flowers the stamens and carpels are so related to one another in position that when pollen is being shed some of it may fall upon the stigma. Even the visit of an insect, which usually results in cross-pollination, may result in self-pollination.

It must not be understood that only cross-pollination is really provided for, and that when self-pollination occurs it is more or less of an accident. In addition to the numerous cases of what may be called accidental self-pollination in flowers usually cross-pollinated, self-pollination is definitely provided for more extensively than once was supposed. It is found that many plants, as violets, for example, in addition to the usual showy insect-pollinated flowers, produce flowers that are not at all showy, that in fact do not open, and are often not prominently placed. These inconspicuous closed flowers are called *cleistogamous flowers;* and in these flowers self-pollination is necessary, and very effective in producing good seed.

146. Yucca and Pronuba.—This is a remarkable case of self-pollination by means of an insect. *Yucca* is a plant of the southwestern arid regions of North America, and *Pronuba* is a moth; and the two are very dependent upon each other. The bell-shaped flowers of *Yucca* hang in great terminal clusters. In each pendent flower (Fig. 237) there are six hanging stamens, and an ovary ribbed lengthwise, with a funnel-shaped stigmatic opening in its top (Fig. 238). The numerous small ovules occur in rows beneath the furrows.

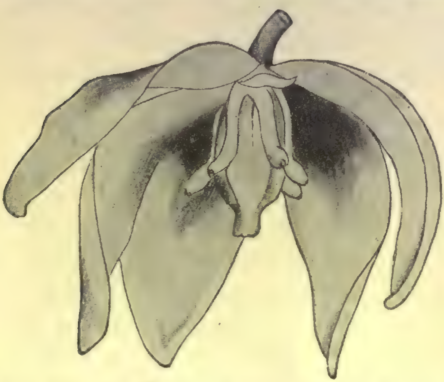

Fig. 237.—The pendent flower of *Yucca*, showing position of stamens and the ribbed ovary.—After Riley and Trelease.

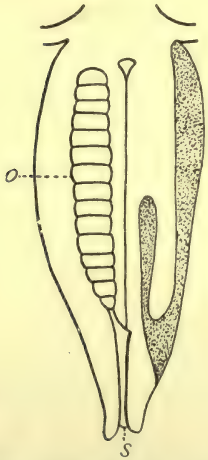

Fig. 238 —Longitudinal section of an ovary of *Yucca*, showing the funnel-shaped stigmatic opening (*s*), and the rows of ovules attached to the wall (*o*).—After Riley and Trelease.

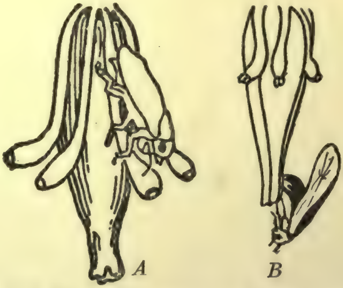

Fig. 239.—The position of *Pronuba* on the stamen of *Yucca* when collecting pollen (*A*) and when thrusting it into the stigmatic funnel (*B*).—After Riley and Trelease.

During the day the small female *Pronuba* rests quietly within the flower, but at dusk becomes very active. She travels down the stamens, and resting on an open pollen sac scoops out the somewhat sticky pollen with her front legs (Fig. 239, *A*). Holding the little mass of pollen against her body, she runs to the ovary, stands astride one of the furrows, and piercing through the wall with her ovipositor deposits an egg in an ovule. After depositing several eggs in this way, she runs to the top of the ovary and begins to crowd into the funnel-shaped stigmatic cavity the mass of pollen she has collected (Fig. 239, *B*). These actions are repeated several times, until many eggs have been deposited and repeated pollination has been effected. As a result of this, seeds are formed which develop abundant nourishment for the moth larvæ, which become mature and bore their way out through the wall of the capsule (Fig. 240).

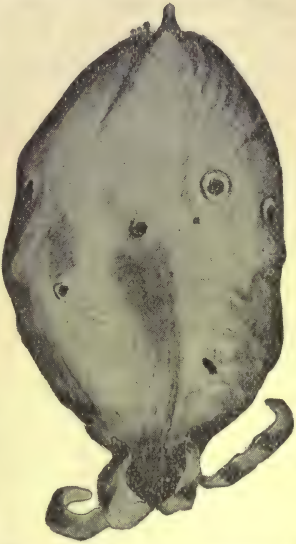

FIG. 240.—A mature capsule of *Yucca*, showing perforations made by larvæ of *Pronuba* in escaping. — After RILEY and TRELEASE.

147. **Cross-pollination.**—In those flowers in which cross-pollination is the rule, self-pollination is hindered in a variety of ways. In the cases about to be considered, stamens and carpels are together in the same flower; of course, in diœcious plants there can be no such thing as self-pollination. It is necessary to remember also that when the stigma is ready to receive the pollen, it excretes upon its surface a sweetish, sticky fluid, which holds and feeds the pollen, inducing the development of pollen tubes.

In this condition the stigma is said to be ready or mature. The pollen is mature when it is ready to fall out of the pollen sacs or to be removed from them. In obtaining nectar or pollen as food, the visiting insect receives pollen on some part of its body which will be likely to come in contact with the stigma of the next flower visited.

Cross-pollinating flowers may be illustrated under three heads, distinguished from one another by their methods of hindering self-pollination; but it must be understood that almost every kind of flower has its own way of solving the problems of pollination. It is an exceedingly interesting and profitable exercise for the student to examine as many cross-pollinating flowers as possible, with the view of determining in each case how self-pollination is hindered, how cross-pollination is secured, and how the visits of unsuitable insects are discouraged.

(1) *Position.*—In these cases the pollen and the stigma are ready at the same time; but their position in reference to each other, or in reference to some conformation of the flower, makes it unlikely that the pollen will fall upon the stigma. The three following illustrations, selected from hundreds, may be given:

In the family (*Leguminosæ*) to which the pea, bean, etc., belong,

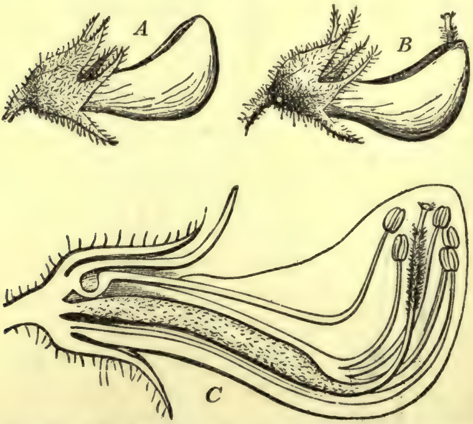

Fig. 241.—Rose acacia: *A*, keel projecting from hairy calyx, the other petals having been removed; *B*, protrusion of tip of style when keel is depressed; *C*. section showing position of parts within keel.—After Gray.

the several stamens and the single carpel are in a cluster enclosed in a boat-shaped structure (*keel*) formed by two of the petals (Fig. 241). The stigma is at the summit of the style and projects somewhat beyond the pollen sacs, some of whose pollen lodges on a hairy zone on the style below the stigma. While the stigma is not altogether secure from receiving some pollen, the position does not favor it. The projecting keel is the natural landing place for a bee visiting the flower; and it is so inserted that the weight of the insect depresses it, and the stigma comes in contact with its body. Not only does the stigma strike the body, but by the glancing blow the surface of the style is rubbed against the insect; and upon this style, below the stigma, the pollen has been shed and is rubbed off against the insect. At the next flower visited the stigma is likely to strike the pollen obtained from the previous flower, and the style will deposit a new supply of pollen. It is interesting to press down slightly the keel of such a flower and see the style apparently dart out.

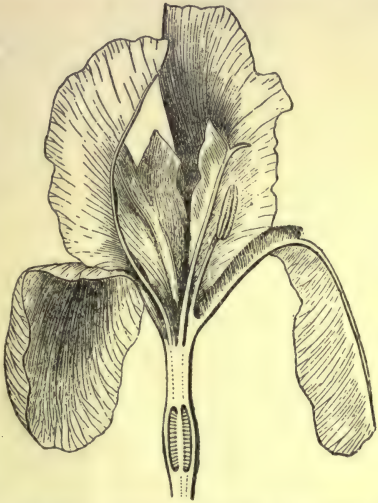

Fig. 242.—Longitudinal section of flower of iris, showing a single stamen between the drooping petal and the petal-like style; the stigmatic shelf is seen above the stamen, at the top of the style; the nectar pit is at the junction of petal and stamen. —After Gray.

In the iris or common flag, each stamen is in a kind of pocket between the petal and the petal-like style; while the stigmatic surface is on the top of a flap or shelf which the style sends out as a roof to the pocket (Fig. 242). With such an arrangement it would seem impossible for the pollen to reach the stigma unaided. The nectar is in a little pit at the bottom of the pocket. As the insect crowds its way into the narrowing pocket, its body is dusted by the pollen; and when it visits the next flower, and pushes aside the stigmatic shelf, it is likely to deposit upon it some of the pollen previously received.

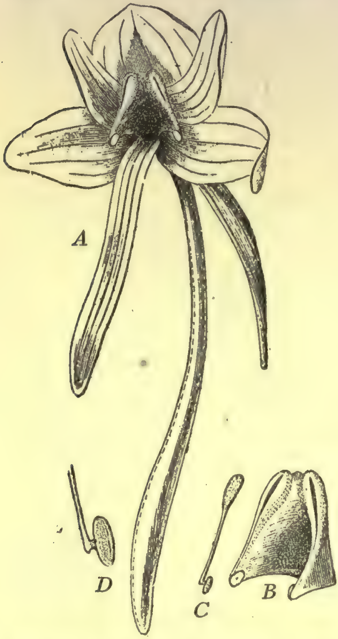

Fig. 243.—Flower of rein orchis: *A*, complete flower, showing three broad sepals, three narrower petals (one of which forms the long lip and the much longer spur), two pollen-sacs, between which extends the concave stigmatic surface (at the bottom of which the opening to the tube is seen); *B*, more enlarged view of pollen sacs, stigmatic surface, and buttons; *C*, a pollinium removed; *D*, a button enlarged.—After Gray.

In the orchids, remarkable for their strange and beautiful flowers, the story of pollination is still more complicated. There are usually two pollen sacs, and the pollen grains are not dry and powdery, but cling together in a mass (*pollinium*), which must be pulled out bodily. An illustration of a common method of pollination may be obtained from the common rein orchis (Fig. 243). Each of the two pollen masses terminates in a sticky disk or button; and between them extends the concave stigmatic surface, at the bottom of which is the opening into the long tube-like spur in the bottom of which the nectar is found. Such a flower is adapted to the large moths, with long proboscides which can reach the bottom of the tube. As the moth thrusts its proboscis into the tube, its head is pressed against the sticky button on each side, so that when it flies away these buttons stick to its head and the pollen masses are torn out. When the next flower is visited these pollen masses are thrust against the stigmatic surface.

(2) *Consecutive maturity.*—In these cases pollen and stigma of the same flower are not mature at the same time. This is a common method of preventing self-pollination, and it is evident that it is effective. When the pollen is being shed, the stigma is not ready to receive; or when the stigma is ready to receive, the pollen is not ready to be shed.

When the flowers of the ordinary figwort first open, the style bearing the stigma at its tip is found protruding from the urn-like flower, while the four stamens are curved down into the tube, and are not ready to shed their pollen (Fig. 244, *A* and *B*). At some later time, the style bearing the stigma wilts, and the stamens straighten up and protrude from the tube (Fig. 244, *C*). In this way, first the

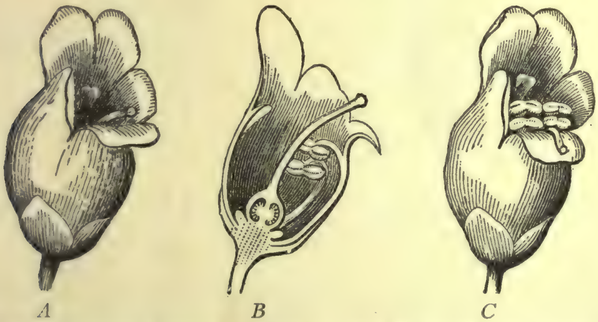

FIG. 244.—Protogynous flower of figwort: *A*, first stage, with stigma receptive; *B*, section of *A*, showing stamens within the corolla; *C*, second stage, with stigma past and anthers in position for shedding.—After GRAY.

receptive stigma, and afterward the shedding pollen sacs occupy the same position. A visiting insect will probably find flowers in both conditions; and, while striking against protruding and shedding pollen sacs in some flowers, it strikes against a protruding stigma in other flowers, and thus carries pollen from one to the other. Such flowers are called *protogynous*, which means "pistil first."

More frequently, however, flowers are *protandrous*, which means "stamens first." For example, when the showy flowers of the common fireweed, or great willow herb, first open, the eight shedding stamens project prominently, the style being sharply curved downward and backward, carrying the stigmatic lobes well out of the way (Fig. 245, *A*). Later, the stamens bend away and the style straightens up and exposes the stigma (Fig. 245, *B*). The result of the visits of an insect is the same as in the case of the protogynous flowers. So many cases of protandrous flowers occur among common wild and cultivated plants that illustrations should be discovered easily.

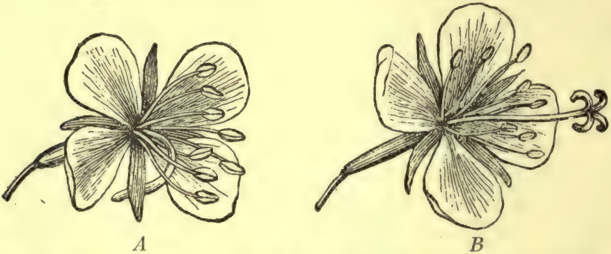

Fig. 245.—Protandrous flower of willow herb: *A*, first stage, with anthers in position for shedding and style curved downward; *B*, second stage, with anthers past and stigmatic lobes in position for receiving pollen.—After Gray.

(3) *Difference in pollen.*—In these cases there are generally two forms of flowers, which differ from each other in the relative lengths of their stamens and styles. In the accompanying illustration it will be seen that in one

flower the stamens are short and included in the tube, while the style is long and projecting, with the four stigmatic lobes exposed well above the corolla (Fig. 246, *A*).

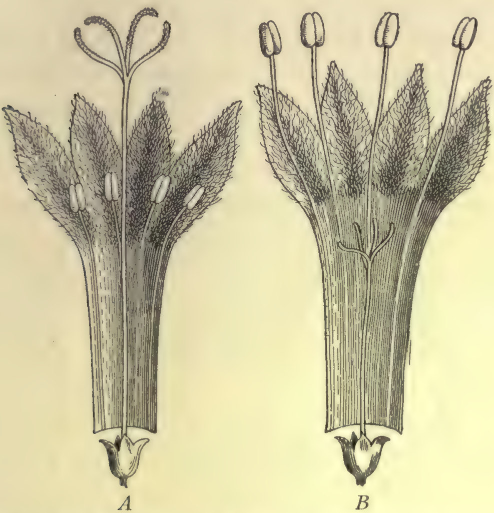

Fig. 246.—Flowers of *Houstonia*: *A*, form with short stamens and long style; *B*, form with long stamens and short style.—After Gray.

In the other flower the relative lengths are exactly reversed, the style being short and included in the tube, and the stamens long and projecting (Fig. 246, *B*). It appears that the pollen from the short stamens is more effective upon the short style; and that the pollen from the long stamens is more effective upon the long style. The body of the visiting insect fills the corolla tube and projects above it. In visiting flowers of both kinds, one region of the body receives pollen from the short stamens, and another region from the long stamens. In this way the insect is soon carrying about two bands of pollen, which come in contact with corresponding stigmas.

148. **Figs.**—Perhaps the most remarkable case of an intimate relationship between insects and flowers is that which exists between a small wasp (*Blastophaga*) and the cultivated fig. The full story is too intricate and variable for presentation here, but a very general outline may give some little idea of the situation. The flowers of the fig are borne in a very peculiar way. What is called a fig is a hollow structure (Fig. 247, *A*), completely closed except for a minute opening at the top, and bearing small flowers in large numbers upon the inner wall (Fig. 247, *B*). Figs are diœcious, so that some trees bear only figs with staminate flowers (Fig. 247, *C*), and others only figs with pistillate flowers (Fig. 247, *D*). The fig that has been cultivated for very many centuries in countries about the Mediterranean is the pistillate tree. In order to make it fruit properly, fig-bearing branches from staminate trees are hung in the pistillate trees. These staminate figs were called "wild figs" or *caprifigs*, and the process of placing them on the pistillate tree was called *caprification*.

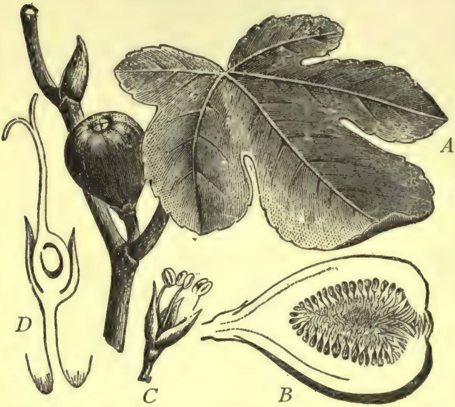

Fig. 247.—The fig: *A*, branch bearing a fig; *B*, section of fig showing flowers within; *C*, staminate flower; *D*, pistillate flower.—After Wossidlo.

Only in recent times has the meaning of this very ancient process become known. As the plants are diœcious, caprification is evidently bringing the staminate flowers near enough to the pistillate flowers to secure a transfer of the pollen. As both kinds of flowers are enclosed in the fig, it is evident that neither the wind nor an ordinary insect can transfer the pollen. This is effected by the small fig wasp that passes its whole existence within the figs. Its real home is the staminate fig (caprifig), and there it deposits its eggs and dies. The new generation of fig wasps crawl out of the old fig, and entering another one that is young deposit their eggs and die, and so on. A staminate fig-tree usually bears three crops of caprifigs each year, the tree never being without a crop; and so three generations of fig wasps are produced in the year, and there is always a home for them.

When a branch bearing staminate figs is placed in a tree bearing pistillate ones, the young wasps crawling out of the former enter the latter, which at this stage closely resemble the caprifigs. Having entered, the wasps find themselves in a trap, for the flower structures are such that they cannot deposit eggs properly. But their bodies are covered with pollen from their former home, and running about among the pistillate flowers they pollinate them very completely. As a consequence, the pistillate fig ripens, forms numerous seeds, and acquires the peculiar nutty flavor that characterizes it.

Pistillate figs ripen without this process, but they do not set seed nor acquire the characteristic flavor, nor can they be dried for shipping. They can only be used as fresh figs, and are not at all the ordinary figs of commerce, known as Smyrna figs. During the last years of the past century the United States Department of Agriculture, after several failures, succeeded in introducing the fig wasp into California, so that real Smyrna figs are now being grown in our own country.

149. **Hybrids.**—In the transfer of pollen by wind and insects, some of it may reach stigmas belonging to a different kind of plant. If this plant is nearly related to the one that has produced the pollen, fertilization may result.

When the seeds formed in this way germinate, they produce plants that are called *hybrids;* that is, plants whose two parents belong to different species or races. The hybrid usually shows some combination of the characters of both parents, but it may be very different from either.

In this way new kinds of plants often arise in nature, and advantage is taken of this fact to produce new forms in cultivation. This cross-pollination between plants of different kinds, resulting in cross-fertilization, is usually spoken of simply as *crossing,* and the use of crossing in producing new forms will be spoken of more fully in the chapter on plant breeding. An illustration of what is meant by hybrids may be obtained from corn. There are several races of corn that differ in the color of the grains, which are white, yellow, red, or lead-colored. If a white race be crossed with a red race, the resulting ears will be hybrids, and will very likely show both colors in the same ear. When the grains are sown and produce new plants, these plants are hybrids and will show resemblances to both parents.

CHAPTER XV

SEED-DISPERSAL

150. **Reasons for dispersal.**—If all seeds dropped about the parent plants, there soon would not be room enough for any more to grow, and those that did grow would interfere with one another seriously. It is of advantage both to the parent plant and to the young plants for the seeds to be scattered beyond the reach of such rivalry. Accordingly, there are many ways by which seeds are dispersed, and sometimes they are carried to great distances. When fruits open to discharge seeds, the seeds themselves are scattered; but when fruits do not open, the fruit itself is transported.

151. **Dispersal by discharge.**—In some plants there is a mechanical discharge of seeds provided for in the structure of the seed-vessel, such fruits often being called

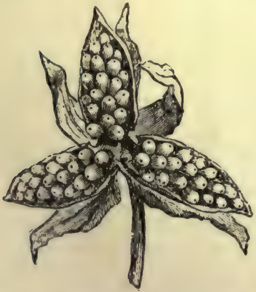

FIG. 248.—The fruit of violet discharging seeds. — After BAILLON.

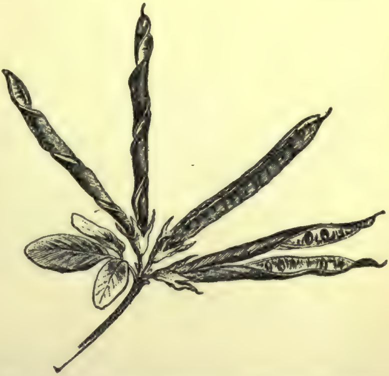

FIG. 249.—The pods of a wild bean (*Lotus*) twisting in discharging seeds. — After BAILLON.

sling-fruits. In the violet and the witch-hazel, when the seed-vessel splits, its walls press upon the seeds so that they are pinched out, as a moist apple-seed is projected by being pressed between the thumb and the finger (Fig. 248). When the pod of the wild bean bursts, the two valves twist violently and throw the seeds (Fig. 249). In the touch-me-not, or the balsam, a strain is developed in the growing wall of the seed-vessel, so that at rupture, which may be brought about by slight pressure, the pieces suddenly curl up and throw the seeds. The squirting cucumber is so named because it becomes very much distended with water, which is finally forcibly ejected along with the mass of seed. In tropical forests there are plants whose large seed-vessels explode with a loud report.

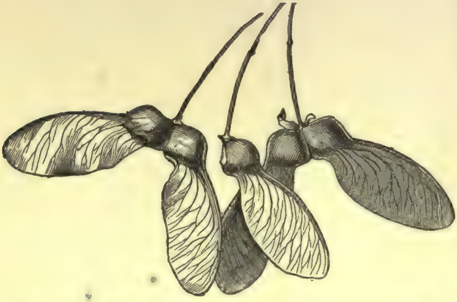

FIG. 250.—Winged fruit of maple.—After KERNER.

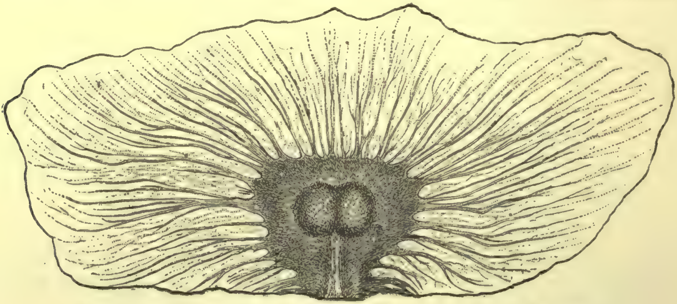

FIG. 251.—Winged seed of *Bignonia*.—After STRASBURGER.

This method may be regarded as the poorest of all the methods of dispersal, for at the very best no seed-vessel can discharge its seeds more than a very short distance.

152. **Dispersal by currents of air.**—Many seeds are so light as to be carried about by currents of air. Ordinarily, however, the wind-dispersed seeds or fruits develop special appendages to aid in their flight, commonest among which are wings and tufts of hair. For example, wings are developed by the fruit of maples (Fig. 250) and elms, and by the seeds of catalpa and its allies (Fig. 251). Plumes and tufts of hair are developed by the seed-like fruits of thistle, dandelion (Fig. 252), and many of their relatives (Fig. 253); and by the seeds of milkweeds (Fig. 254), willow herbs (Fig. 255), etc.

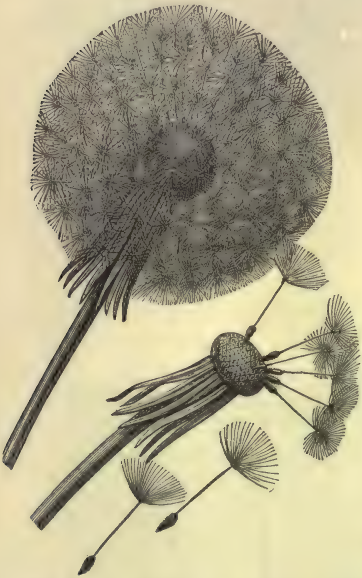

Fig. 252.—Akenes of dandelion with tufts of hair.—After Kerner.

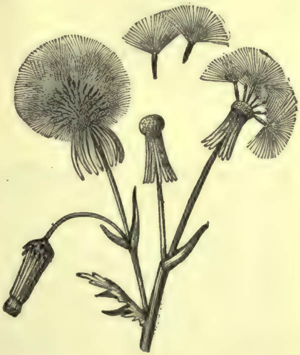

Fig. 253.—Akenes of *Senecio* with tufts of hair.—After Kerner.

On plains, or level stretches, where winds are strong, a curious habit of seed-dispersal has been developed by certain plants known as tumbleweeds or field rollers (Fig. 256). These plants are profusely branching annuals with a small root system in light or sandy soil. When the work of the season is over, and the absorbing rootlets have shriveled, the plant is easily broken from its

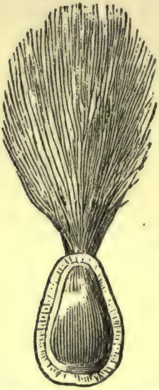

Fig. 254.—Seed of milkweed with tuft of hair.—After Gray.

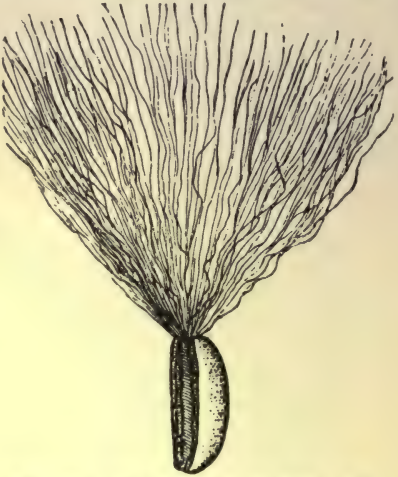

Fig. 255.—Seed of willow herb with tuft of hair.

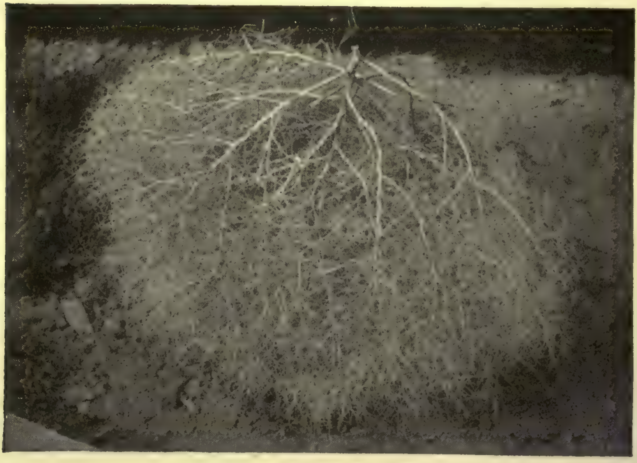

Fig. 256.—A common tumbleweed.

roots by a gust of wind, and is trundled along the surface like a light wicker ball, the ripe seed-vessels dropping their seeds by the way. In case of an obstruction, such as a fence, great masses of these tumbleweeds may be seen lodged against the windward side.

This method of dispersal is far more effective than the mechanical discharge; but it is fitful, and its range usually is not very great. Thistle-down may be floated into a neighboring field, and a strong wind may carry the comparatively heavy-winged fruits of the maple and the elm some distance; but at best the scattering is only over a neighborhood.

153. **Dispersal by currents of water.**—Many seeds are buoyant, or become so after soaking in water, and may be carried great distances by currents. For example, the banks and flood-plains of streams may receive seeds from a wide area, dependent on the extent of the drainage system. Along the lower stretches of rivers such as the Mississippi, the Missouri, or the Ohio, almost every season new plants are added to those growing along the banks, and some of them may have come from great distances. This kind of distribution, therefore, may become almost continental in extent.

Still more far-reaching is the dispersal brought about by oceanic currents, both by waves carrying seeds along the coast, and also by the deeper currents that extend from continent to continent or to oceanic islands. It has been found that many seeds can endure even prolonged soaking in sea-water and then germinate. From a series of experiments, Darwin estimated that at least fourteen per cent of the seeds of British plants can retain their vitality in sea-water for twenty-eight days. At the ordinary rate of movement of ocean currents, this length of time would permit seeds to be transported over a thousand miles. It is thought that the appearance on islands of certain plants belonging to an adjacent continent may often be explained in this way.

154. **Dispersal by animals.**—Only a few illustrations of this very large subject can be given. Water-birds are great carriers of seeds, which are contained in the mud clinging to their feet and legs. This mud from the borders of ponds is usually completely filled with seeds of various plants. One has no conception of the number until it is actually computed. The following extract from Darwin's *Origin of Species* illustrates this point:

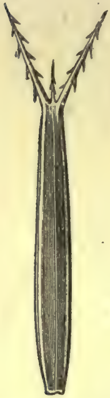

FIG 257.—Akene of Spanish needles with barbed appendages.—After KERNER.

> "I took, in February, three tablespoonfuls of mud from three different points beneath the water, on the edge of a little pond. The mud when dried weighed only 6¾ ounces; I kept it covered up in my study for six weeks, pulling up and counting each plant as it grew; the plants were of many kinds, and were altogether 537 in number; and yet the viscid mud was all contained in a breakfast cup!"

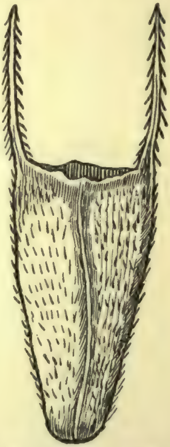

FIG. 258.—Akene of beggar-ticks with barbed appendages.—After BEAL.

Water-birds are generally high and strong fliers, and the seeds may be transported thus to the margins of distant ponds and lakes, and so become very widely dispersed.

In many cases seeds or fruits or heads develop grappling appendages of various kinds, forming the various burs, which lay hold of animals brushing past; and so the seeds are dispersed. Common illustrations of fruits with grappling appendages are Spanish needles

(Fig. 257), beggar-ticks (Fig. 258), stick seeds, etc.; and similar appendages are developed in connection with the involucres of cockle-bur (Fig. 259, *A*), burdock (Fig. 259, *B*), etc.

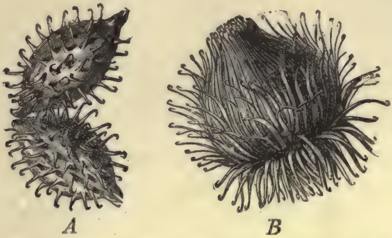

FIG. 259.—Heads of cockle-bur (*A*) and burdock (*B*), showing grappling appendages of the involucre.—After KERNER.

Fleshy fruits are attractive as food to certain birds and mammals. Many of the seeds (such as those of grapes) may be able to resist the attacks of the digestive fluids and escape from the alimentary tract in a condition to germinate. As if to attract the attention of fruit-eating animals, fleshy fruits usually become brightly colored when ripe, so that they are plainly seen in contrast with the foliage.

CHAPTER XVI

MONOCOTYLEDONS

155. **Classification.**—The Angiosperms are so numerous that it requires much time through several seasons to get acquainted fairly well with them in any one neighborhood. The elementary student should begin at once to cultivate this acquaintance by learning to recognize the most prominent groups and the most common representatives of each group. For example, there should be no difficulty usually in recognizing whether a given plant is a Monocotyledon or a Dicotyledon; since the floral number, the venation, and the stem arrangement of vascular bundles will determine that in most cases.

In each of these two great divisions of Angiosperms, however, there are numerous *families*, and one should become acquainted early with the most conspicuous families of a neighborhood. For example, a very conspicuous family of the Monocotyledons in every neighborhood is that which contains the grasses; but in every neighborhood there will occur also ten to twenty other prominent families of Angiosperms that deserve recognition.

A family is made up of smaller groups called *genera* (singular *genus*). For example, in the great family to which the asters belong, the different asters resemble one another more than they do any other members of the family; and so there is the aster genus. In the same family the different goldenrods are grouped together in a goldenrod genus. The different kinds of aster or of goldenrod are called *species*. Therefore, a group of related *species* forms a *genus;* and a group of related *genera* forms a *family*. An acquaintance with the plants of a neighborhood should begin by learning to recognize not merely important families but also conspicuous and common genera and species.

The technical name of a plant is the combination of its generic and specific names, the former always being written first. For example, *Quercus alba* is the name of the common white oak, *Quercus* being the name of the genus to which all oaks belong, and *alba* the specific name that distinguishes this oak from other oaks. No other names are necessary, as no two genera of plants can bear the same name, and no two species of a genus can have the same name.

The so-called *Manuals* or *Keys* are books that contain descriptions of plants, so arranged that one who knows the meaning of the terms used can find the name of any plant described. Ability to use such a manual is very desirable to cultivate, for it is the most accurate and effective method of forming a speaking acquaintance with plants.

156. **Families of Monocotyledons.**—About forty monocotyledonous families are recognized, containing numerous genera and about twenty thousand species. Four families will be selected, which include the great majority of Monocotyledons; and these should be recognized at sight. These families are conspicuous in numbers, or in appearance or in usefulness; and for any or all of these characters they deserve acquaintance.

157. **Grasses.**—The Grass Family (*Gramineæ*) is one of the largest groups of plants. It is world-wide in its distribution, and is remarkable in its display of individual plants, often growing so densely over large areas as to form a close turf.

The flowers are very simple having no calyx or corolla, and the grain is the characteristic seed-like fruit. The flowers occur in small close clusters, and associated with them are peculiar bracts characteristic of the family (Fig. 260). For example, these bracts form the so-called chaff of wheat and other cereals, where they persist and more or less envelop the grain. These little clusters of bracteate flowers are arranged to form either a loose and spreading general cluster, as in red top and oats (Fig. 262), or else a compact, spike-like cluster, as in timothy and wheat (Fig. 261).

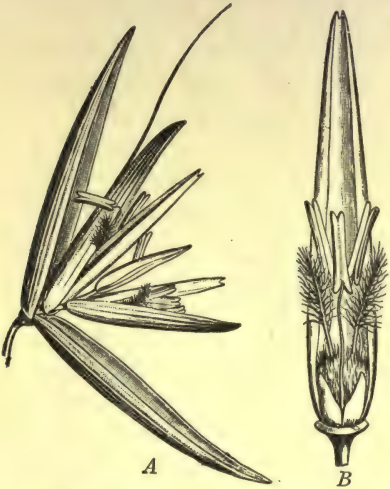

Fig. 260.—Oats: *A*, part of a flower-cluster, showing the bracts, in the axils of which flowers appear; *B*, a single flower, with its enveloping bract, three stamens, and pistil whose ovary bears two plumose styles.—After Baillon.

When the uses of grasses are considered, it becomes evident that this is by far the most important family of plants to man. It is possible to suggest only some of the conspicuous forms.

(1) Cereals.—This group includes those grasses that are cultivated for their seed-like fruits or grains, and they represent the chief interest of agriculture. What cereals mean as a food-supply for the world is too well known to need explanation. The most extensively cultivated cereals are as follows:

Wheat.—This is certainly the best known and most valuable of all cereals. The original home of wheat is unknown, for it has been cultivated from the very earliest times. It is a crop peculiarly adapted to regions of cold winters, and hence the greatest supply comes from temperate regions. The Northern United States and Canada have vast areas especially well-adapted to the cultivation of wheat; and in 1899 (last census) the United States alone produced more than one-fourth of the wheat of the world, being the greatest wheat-producing country. In this production the chief wheat-growing States, in the order of their output, were Minnesota, North Dakota, Ohio, and South Dakota.

The varieties of wheat are very numerous, and new ones are constantly being produced in the effort to get the very best variety for every combination of climate and soil. There are spring and winter wheats, bearded and beardless wheats (Fig. 261), soft and hard wheats, and wheats of various colors. Winter wheat is sown in the fall, and hence must be a variety able to endure the winter; while spring wheat is sown as early in the spring as possible. Since wheat grows best during the cool part of the year, it is very conveniently related to the corn crop, which makes its chief growth during the warm months. The time of harvesting varies with the latitude, ranging from early in May in Texas to August in some northern States.

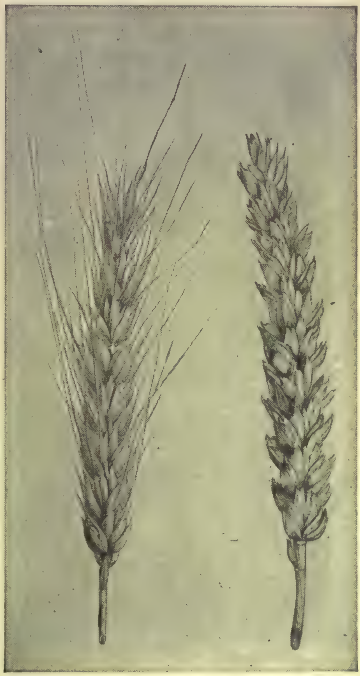

FIG. 261.—Bearded and beardless wheat. —After ENGLER and PRANTL.

Oats.—Oats may be distinguished from wheat, rye, and barley by the flower clusters being loose and spreading (Fig. 262), rather than in compact cylindrical clusters (spikes). It also has been cultivated from the most ancient times, and to-day the United States and Russia produce the greatest crops. Oats are usually sown as early in the spring as possible, developing best in the cooler weather; and in northern latitudes the crop matures in ninety days or less. Oats do not require so rich soil as wheat, and hence can be grown successfully where wheat would not thrive. In 1899 the United States produced more bushels of oats than of wheat.

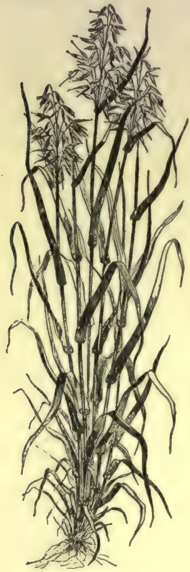

Fig. 262.—Oats. After Baillon.

Rye.—This cereal does not seem to have been so long in cultivation as the

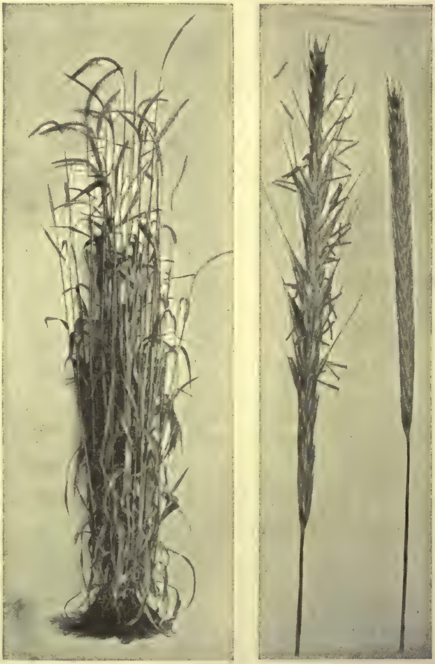

Fig. 263.—Rye

others (Fig. 263). It is extensively cultivated in Northern Europe; and Russia is the greatest rye-producing country in the world, producing more bushels of rye than the United States produces bushels of wheat. The rye crop of the United States is very small comparatively, being less than one-twenty-fifth as large as the wheat crop, and less than one-thirtieth as large as the oat crop. Rye can grow in regions too cold for wheat and on soils too poor for any other grain; in fact it does not thrive well in rich soils. There are spring and winter varieties. The latter is the one chiefly cultivated, being sown in the fall and harvested usually in June.

Barley.—This is one of the most ancient of cereals in cultivation; and, as it grows wild in western Asia, this is thought to be its original home (Fig. 264). It grows through a greater range of latitude than any other cereal, its cultivation extending from Iceland and Norway to India. It demands in general the well-prepared and well-drained soil necessary for wheat. Its growing period is shorter than that of wheat, for it is very common to sow it after and to harvest it just before spring wheat. In the United States the barley crop in 1899 was nearly three times as great as that of rye, California producing more than one-fourth of it, and Iowa, Minnesota, and Wisconsin following in order. While barley is used in feeding, as grain, hay, and straw, its most conspicuous use is by brewers in the

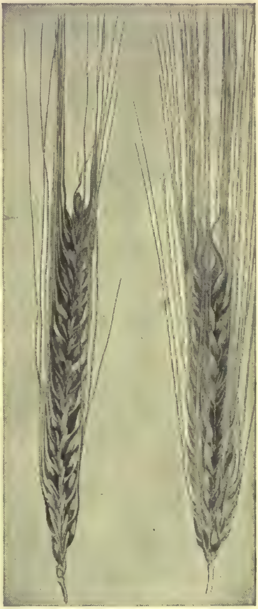

FIG. 264.—Barley.—After ENGLER and PRANTL.

process of malting; and the best malting barley in the world is grown in eastern England.

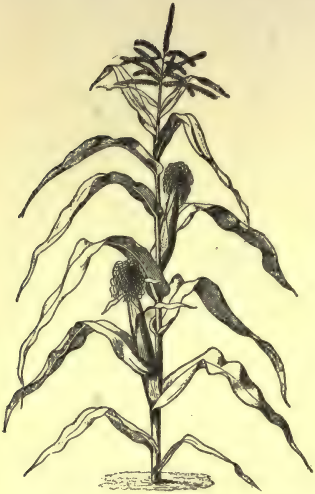

FIG. 265.—Corn.—After ENGLER and PRANTL.

Corn.—Indian corn, or maize as it should be called, is peculiarly an American crop (Fig. 265). It is thought to be of American origin and was cultivated by the native tribes long before the coming of Europeans; and four-fifths of the corn of the world is still produced in the United States. The plant varies in height from dwarf varieties less than two feet, to large varieties fifteen or twenty feet in river bottoms, and even thirty feet and more is reported from the West Indies. The staminate and pistillate flowers occur in separate clusters on the same stalk; that is, the plant is monœcious. The staminate cluster is at the top, and is called the tassel; while the pistillate clusters (ears), with their enveloping bracts (husks), occur in the axils of leaves, the long styles forming the so-called silk.

The prominent groups of corn are dent corn, flint corn, sweet corn, and pop-corn; and each of these has many varieties, differing in certain qualities and also in color, white or yellow grains prevailing. Most of the field corn produced in the United States is dent corn, recognized by the indentation at the top of the grain. The best soil for corn is a rich loam that does not bake during drought, the plowing being deeper than for any other grain. Most of the world's corn is produced in the northern States of the Mississippi Valley; and there planting is done in May, and the crop matures in about five months. The great corn-producing States in their order are Illinois, Iowa, Kansas, Nebraska, Missouri, and Indiana; and in 1899 these States produced nearly three-fifths of the entire crop of the United States.

Aside from its use as a food for man and domestic animals, corn, it is said, enters into the preparation of more than a hundred different articles, in which the husks, the outer part of the stalk, the pith, and the cobs are used. Most of the starch of the United States comes from corn, and much of the whisky and the alcohol. In addition to the various races of field corn, the sugar-containing sweet corn, used in marketing and canning, with its wrinkled grains and short growing period, is well known; and also the small-eared and flinty pop-corn.

While corn is not seriously injured by rusts (§ 84) as are the other cereals, its most common disease is smut, which appears as tumor-like swellings (on stalks, leaves, and ears) full of spores that look like black powder. Smuts are related to the rusts, and their attack on corn has not been prevented so successfully as have their attacks on other cereals.

Rice.—Rice is said to form the principal food of one-half the human race (Fig. 266). A native of the East Indies, it is cultivated now wherever the proper conditions are present. It needs a subtropical climate, and a moist soil that can be flooded artificially at certain seasons. Far the greatest amount of the rice of the world is produced in

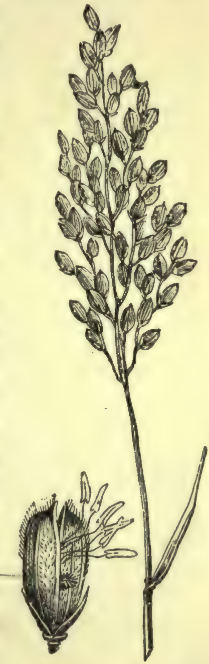
FIG. 266.—Rice.—After WOSSIDLO.

India, China, Japan, and the East Indies; but our own Gulf States are developing the industry rapidly. The Carolina rice is said to be the best in the market, and before the Civil War South Carolina was our great rice-producing State. In 1899, however, Louisiana produced more than twice as much rice as all the other Gulf States combined, South Carolina being second. Rice in the husk is called paddy; and this is the general name also for rice in India.

(2) SUGAR-CANES.—The ordinary sugar of commerce is cane-sugar, which is obtained mostly from sugar-cane; but in Europe it is obtained largely from beets. Sugar-cane is a tropical and subtropical grass, a native of the East Indies, but is cultivated wherever there is a warm climate, a deep rich soil, and abundant moisture. The plant is about the height of corn, but has a much more slender stem, and bears at the summit a very large and spreading flower cluster (Fig. 267). Its cultivation is usually carried on in large plantations, our greatest sugar-producing State being Louisiana. When the canes (as the stems are called) are mature, they are cut, stripped of their leaves, and crushed. Associated with the production of sugar as by-products are the various sirups or molasses.

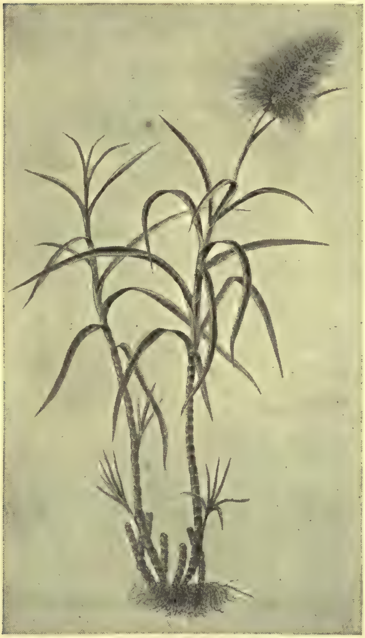
FIG. 267.—Sugar-cane.—After WOSSIDLO.

In 1903, the greatest sugar-producing regions of the world stood in the following order: Cuba, Java, Hawaiian Islands, and Louisiana.

(3) LAWN, PASTURE, AND HAY GRASSES.—This group includes numerous grasses that have been selected for certain combinations of qualities. For example, blue grass is one of the most famous grasses for all these purposes; red top is a prominent pasture grass; and timothy is one of the best hay grasses.

(4) BAMBOO.—In tropical and subtropical countries the huge grasses called bamboos are extremely useful (Fig. 268). Some species reach seventy to one hundred feet in height and a foot in diameter, forming regular groves and forests. Their very hard, light, and tough stems are put to innumerable uses, including house-building, bridge-building, light wickerwork, and weaving of various kinds. The manufacture of fishing-rods from split bamboo is well known; but the ordinary fishing-poles are stems of a kind of bamboo that is native to our Southern States, where it covers extensive areas that are called cane-brakes.

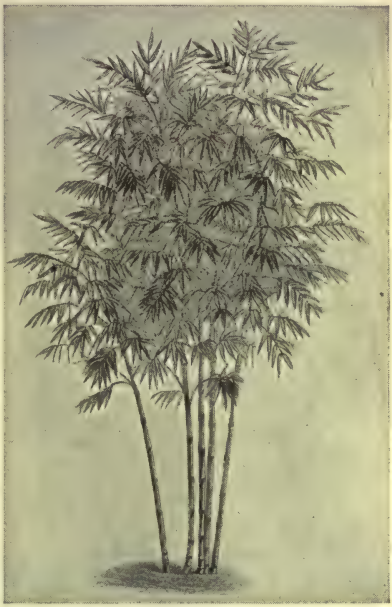

FIG. 268.—Bamboo.—After ENGLER and PRANTL.

158. **Palms.**—The Palm Family (*Palmaceæ*) is the great tree group of the Monocotyledons. Although palms are

characteristic tropical and subtropical plants, they are such well-known, beautiful, and useful forms as to deserve prominent mention. The habit of the body is very familiar, being a conspicuous feature in every tropical landscape. The usually tall, unbranched, columnar trunk bears at its summit a crown of huge leaves, which are of either the pinnate or the palmate type. Besides these palms, there are low forms and branching forms, while the rattan palms

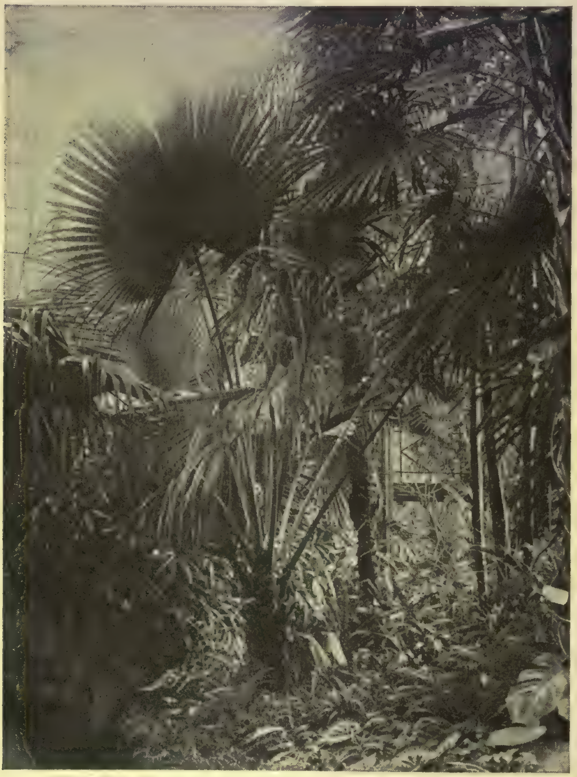

Fig. 269.—A common fan-palm.

have climbing, rope-like stems that sometimes become hundreds of feet long. Species with palmate leaves are spoken of as fan-palms, the palmetto of the Southern States being an illustration (Fig. 269), and also the very interesting Washington palm of the desert region of Southern California and adjacent Arizona (Fig. 270); the others are

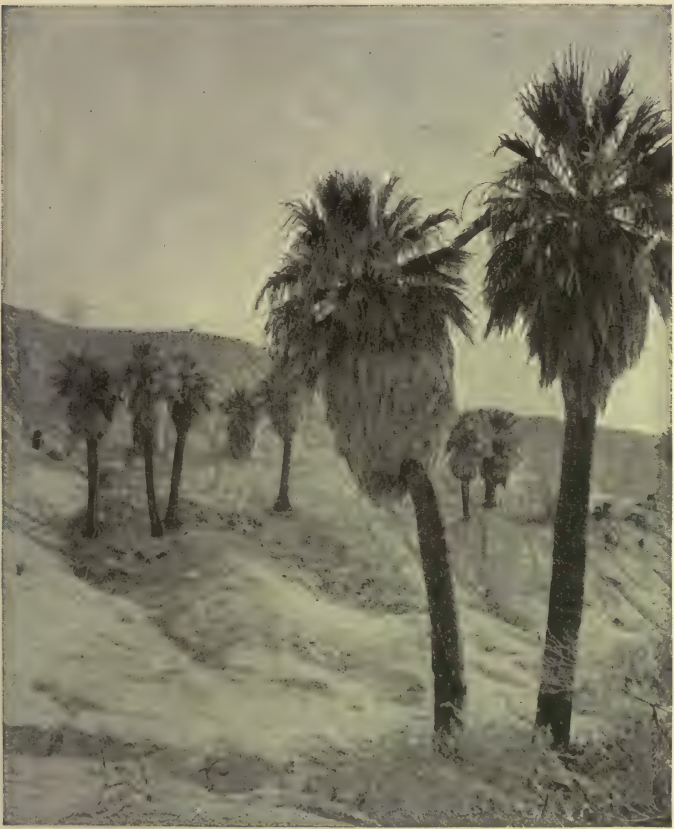

FIG. 270.—The Washington palm; a fan-palm of the desert region of Southern California and adjacent Arizona.—From *World To-day.*

feather palms (Fig. 271). The flower clusters are enormous, each cluster enclosed at first in a huge bract, which is often hard. In usefulness to man no monocotyledonous family exceeds the palms except the grasses. Some of the prominent species are as follows:

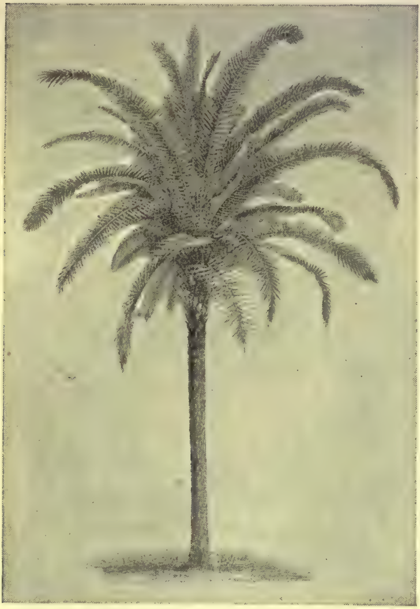

FIG. 271.—A feather palm, closely related to the date-palm.—After ENGLER and PRANTL.

The *coconut-palm* is the most widely distributed palm, being found in all tropical countries, and never very far from the sea, except as planted by man (Fig. 272). Its slender trunk, about two feet in diameter, rises to a height of sixty to one hundred feet and bears a crown of downward curving pinnate leaves. The coconut of commerce is well known. It is really a stone-fruit (§ 143), in which the ovary wall has ripened in two layers: the outer a fibrous husk, corresponding to the flesh in a peach; the inner a heavy bony layer. When on sale, the outer husk has usually been stripped off, and at one end of the bony coat three round black scars are seen, which indicate that the pistil is made up of three carpels. All parts of the plant are used, not only the nuts and the oil from them, but also the leaves, the root, the sap of the young parts, etc.

The *date-palm* finds its most congenial home in Arabia, but is also extensively cultivated in northern Africa (Fig. 273). It becomes a very large tree, thriving in a hot, dry climate and sandy soil; and this makes it invaluable in semitropical desert regions. The enormous yield of a single tree is indicated by the fact that it is long-lived and that it may yield 300 to 500 pounds of dates in a single season. Great interest attaches to the fact that the date-palm promises to become commercially important in certain regions of California and Arizona that seem otherwise to be hopeless from an agricultural point of view, since it thrives in any amount of heat and drought, and can endure more alkali in the soil than any other profitable plant. This is the palm of the Bible and of ancient writings in general. Its habit is shown in Fig. 271.

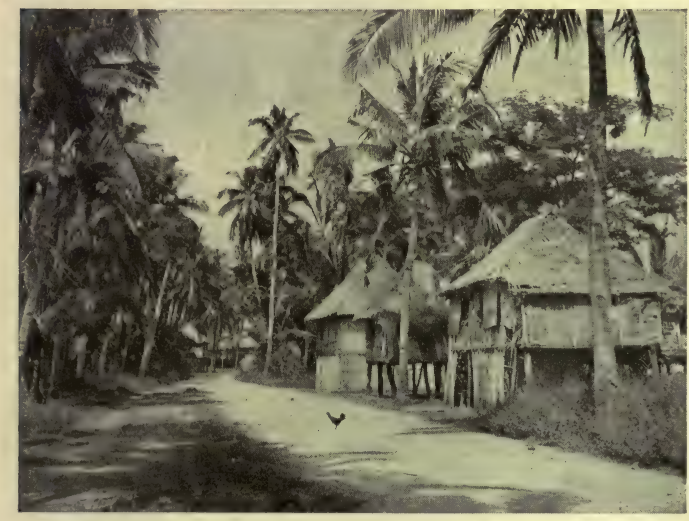

FIG. 272.—Coconut-palms in a Filipino village.—Photograph by RITCHIE.

The *sago-palm* is a native of the East Indies, and is extensively cultivated there. It has an extraordinarily

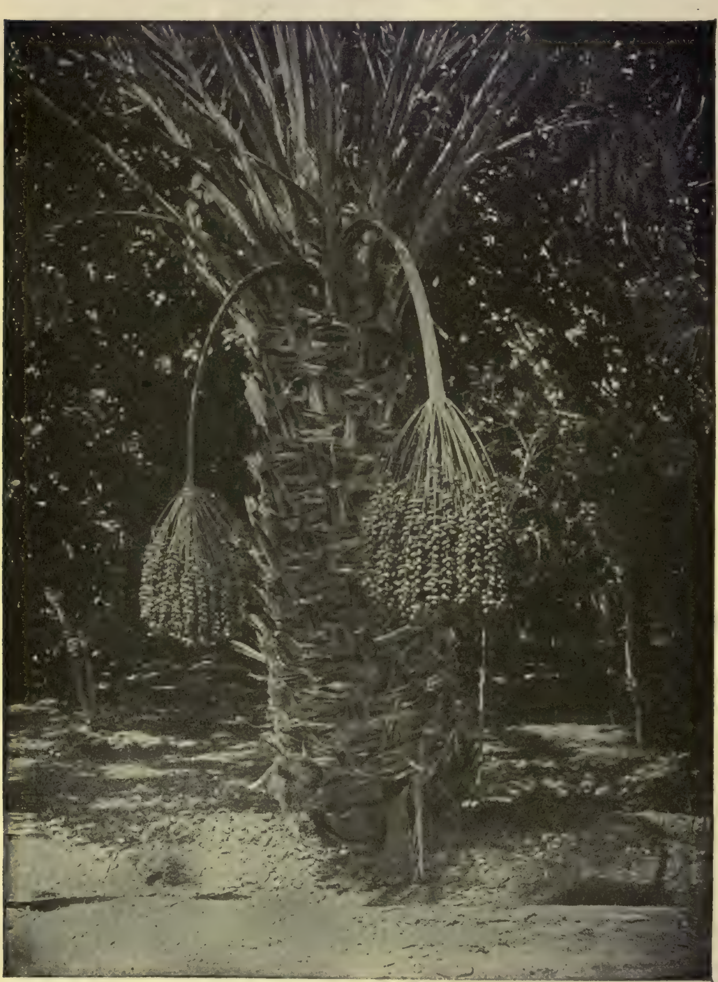

FIG. 273.—Base of a date-palm, showing two fruit clusters and the trunk ensheathed by old leaf bases.

large pith, which is filled with starch; and sometimes, it is said, as much as 700 pounds of pith are obtained from a single tree. This starch reaches Europe and America in the form of sago.

The list of palms and of their uses is a very long one; but the illustrations given will show that the family consists of forms used for the greatest variety of purposes by millions of people.

159. **Lilies.**—In the structure of its flowers the Lily Family (*Liliaceæ*) may be regarded as the typical family of Monocotyledons. With three as the definite flower number, with a brightly colored and often conspicuous corolla or perianth, and with the ovary superior (§ 138), there is no reason why most of the members of the family should not be recognized easily (Fig. 274). Nearly all of them are terrestrial herbs; and they are notably forms with bulbs, rootstocks, etc., which enable them to put up rapidly at the coming of a favorable season. The family is better known for its beauty than for its usefulness. Among the well-known wild and cultivated forms are trilliums, lily-of-the-valley, numerous true lilies, tulips, dog-tooth violet (Fig. 219), star of Bethlehem, and hyacinth; while asparagus and onion are the most common useful forms.

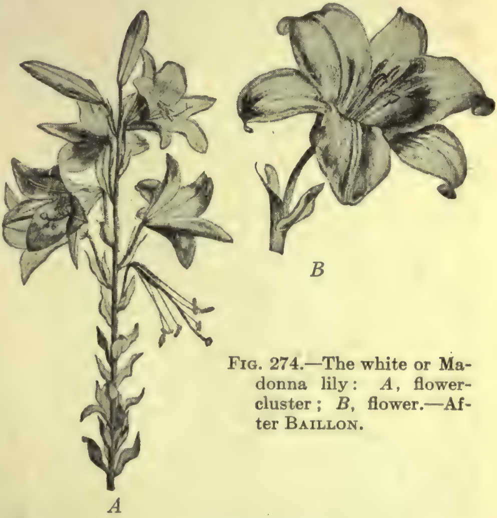

FIG. 274.—The white or Madonna lily: *A*, flower-cluster; *B*, flower.—After BAILLON.

The families most likely to be confused with the lilies are the Amaryllis Family (*Amaryllidaceæ*) and the Iris Family (*Iridaceæ*), but in both of these the ovary is inferior (§ 138) and appears beneath the flower. Among the amaryllis forms (those with six stamens) are narcissus (including daffodils and jonquils), snowdrop, snowflake (Fig. 220), tuberose, and certain so-called lilies. Among the iris forms (those with three stamens) are iris (including the various flags) (Fig. 242), crocus, and gladiolus.

160. **Orchids.**—In number of species the Orchid Family (*Orchidaceæ*) is the greatest family of the Monocotyledons; but orchids are comparatively rare plants, not extensively distributed, and often very much restricted. In actual number of individual plants they are not to be compared with the grasses, or even with the lilies. They are noted for their remarkably irregular flowers, whose bizarre forms and brilliant coloration are associated with insect visits. In fact, the orchids may be said to have specialized in adaptations to insects (§ 147). They can always be recognized among Monocotyledons by their inferior ovary and by the remarkable modification of one of the petals (apparently the lowest one), which always differs from the others in size and form, and is called the *lip*. Sometimes the lip is like an inflated pouch or sac, as in the lady-slipper (Fig. 275); and often it develops a conspicuous hollow spur (Fig. 243). The great display of the family is in the tropics, and there many of them are perching plants (§ 41). The tropical forms are most prized as greenhouse plants, and a good collection of orchids in bloom is exceedingly attractive.

Very little use has been made of orchids, the best known useful product being vanilla, which is extracted from the fruit of a climbing orchid native in Mexico.

161. **Other useful Monocotyledons.**—Two useful and well-known Monocotyledons do not belong to any of these

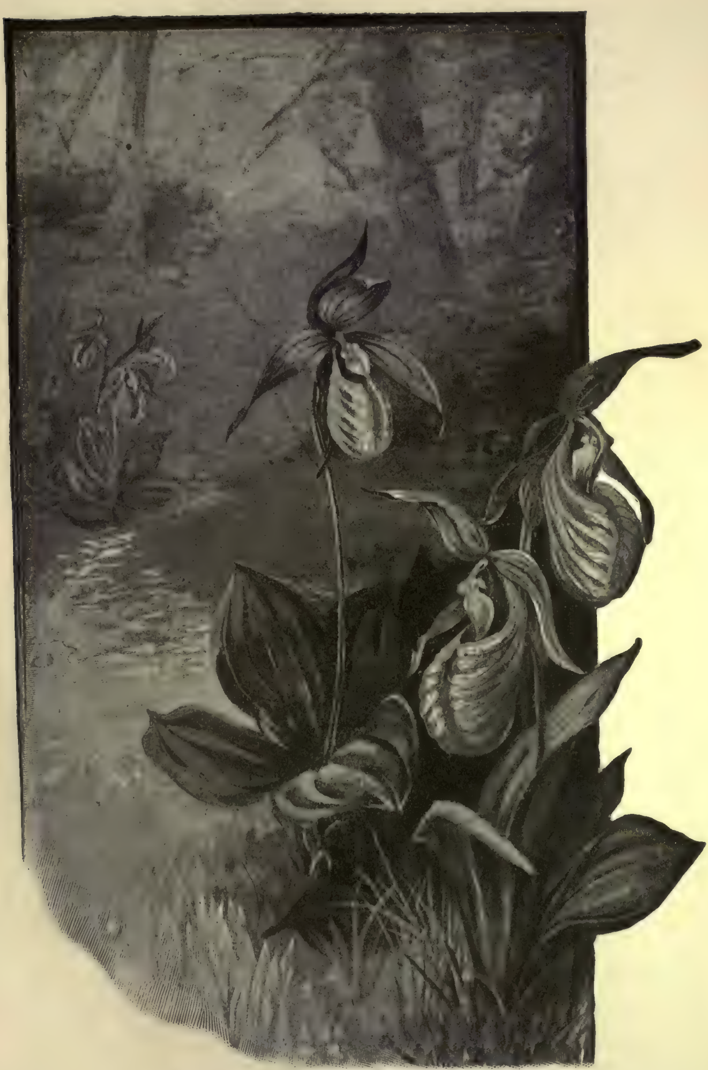

FIG. 275.—Lady-slippers.—After GIBSON.

great and representative families, and they deserve to be mentioned in this general survey.

The *banana* belongs to a small family most nearly related to the orchids; and, although a tropical plant, it is coming into common use as a foliage plant on account of its beautiful leaves, associated with its relative the canna. It grows from ten to forty feet high, although it is an herb, and bears a crown of very large, pinnately veined leaves (Fig. 276). From fifty to one hundred and fifty fruits are produced in a single cluster, and a plant bears only once.

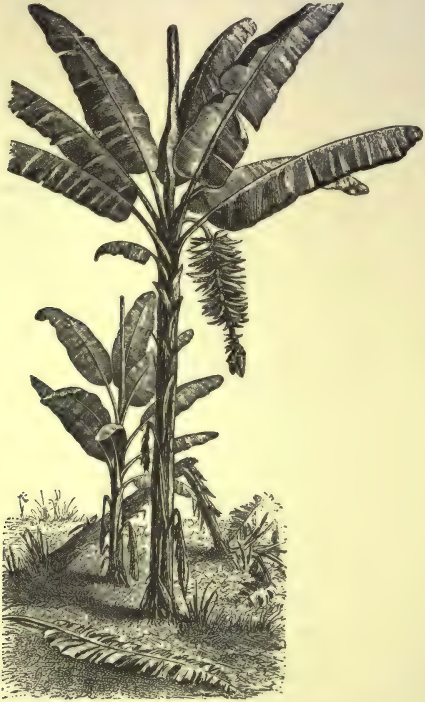

FIG. 276.—A banana plant.—After ENGLER and PRANTL.

There are many varieties of bananas; but the Martinique, with large yellow fruit, is the one most extensively cultivated. The chief banana-producing regions are the West Indies and Central America; but bananas are grown also in Florida, Louisiana, and California.

The *pineapple* is developed by a low plant producing a tuft of stiff, sword-shaped leaves, in the center of which a single pineapple arises (Fig. 277). It is a native of tropical America, and our supply comes chiefly from the West Indies, Bahama Islands, and Florida. The nature of this peculiar fruit has been described (§ 143).

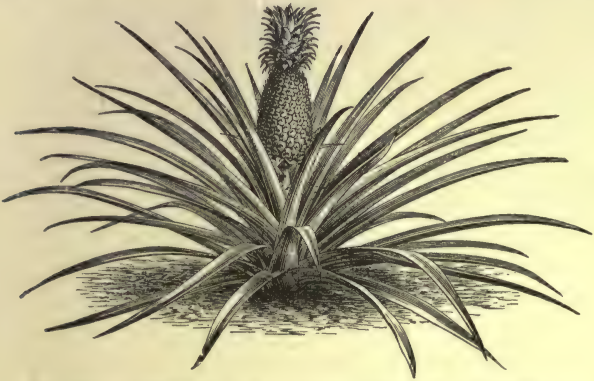

FIG. 277.—A pineapple plant.—From *Dictionary of Gardening.*

CHAPTER XVII

DICOTYLEDONS: ARCHICHLAMYDEÆ

162. The two great divisions of Dicotyledons.—The Dicotyledons are a much larger group than the Monocotyledons, containing more than 200 families and about 100,000 species. Most of them are easily recognized by the floral number five or four, the net-veined leaves, and the arrangement of the vascular bundles of the stem in a hollow cylinder. There are two great divisions of Dicotyledons: the *Archichlamydeæ,* whose sepals and petals are either wanting or entirely separate; and the *Sympetalæ,* whose corollas are sympetalous (§ 133). This is by no means the only difference, but it is the one used to form the names.

The Archichlamydeæ comprise about three-fourths of the families and three-fifths of the species of Dicotyledons, and the group is so extensive and intricate that only a slight acquaintance with it is possible at first. Five conspicuous families or groups are selected on account of their representative character and common occurrence.

163. The tree group.—In the lower stretches of the Archichlamydeæ there are a number of small families that include our most common hardwood or deciduous trees, and this assemblage of conspicuous forms may be considered together, without selecting any special family. They include elms (Fig. 44), sycamore, walnuts, hickories, oaks (Fig. 43), chestnuts, willows, poplars (cottonwoods), birches, beech, etc. These trees are all characterized by their simple and inconspicuous flowers, which are usually monœcious or diœcious (§ 137) and wind-pollinated. A very characteristic flower-cluster occurs in many of these forms, being a spike-like cluster, but having conspicuous scales or bracts subtending individual flowers or small groups of flowers. It is called the *ament* or *catkin;* and familiar illustrations are found on willows (Fig. 278), cottonwoods, birches, and alders (Fig. 279). Both staminate and pistillate flowers, or only one kind, may be in aments.

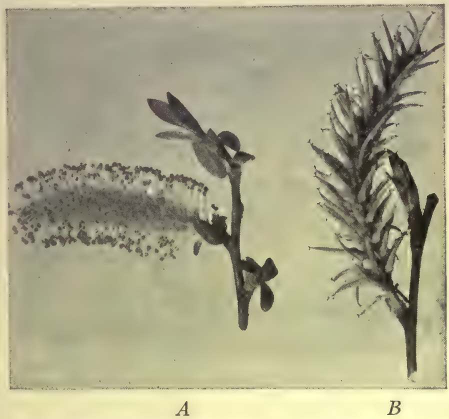

Fig. 278.—Catkins of willow: *A*, staminate; *B*, pistillate.

In higher families with more conspicuous and usually insect-pollinated flowers, other common trees occur, as the tulip-tree (white poplar), magnolia, linden, maple, buckeye, box-elder, locust, sweet-gum, and tupelo (black-gum); and among the Sympetalæ the ash belongs. The very names of these trees suggest the characteristic forms of our great deciduous forest, which once extended in almost unbroken sweep from the prairies to the Atlantic

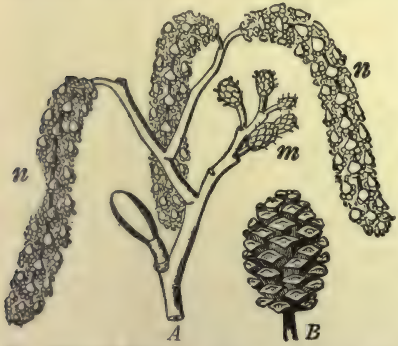

Fig. 279.—Catkins of alder; *A*, branch with staminate (*n*) and pistillate (*m*) catkins; *B*, pistillate catkin in the next year (when the seeds are ripe).—After Warming.

Coast. The beauty and variety of this forest is one of the distinguishing characters of the vegetation of the United States, and its abuse is equally characteristic of our early history. This great forest region of deciduous trees is spoken of in general as the Atlantic forest; and in it the conifers are sparingly represented, either mixed through it or in small patches. In the rich soils of the central States, as in Ohio, Indiana, Illinois, Kentucky, Tennessee, and Missouri, the deciduous forest reaches its culmination in variety, vigor, and purity.

Only one-fourth of our timber comes from these hardwood trees, the other three-fourths being supplied by conifers (§ 128); and among them the oaks are the most useful, furnishing more than one-half the hardwood timber. Next in importance, so far as output is concerned, and in the following order, are tulip-tree (white poplar, furnishing the so-called poplar lumber), maple, elm, poplar (cottonwood), linden (basswood), sweet-gum (red-gum), ash, chestnut, birch, hickory, black walnut, sycamore, etc. In actual market value of the lumber, that is, the comparative value of the same amount of lumber of each kind, the order is as follows: black walnut, elm, oak, ash, tulip-tree (white poplar), chestnut, maple, sweet-gum (red-gum), linden (basswood), poplar (cottonwood), etc. Of course this order of output and of value cannot be a fixed one, but it serves to indicate the situation at the last census.

164. **Buttercups.**—The Buttercup Family (*Ranunculaceæ*), usually called the Crowfoot Family, represents very well the herbs with the simpler flowers that belong to the Archichlamydeæ. Taking an ordinary early spring buttercup as an example, there are five green sepals, five yellow petals, numerous stamens, and a little head of numerous carpels growing as separate pistils. This last character, the distinct carpels, is quite an important feature; and flowers that have it are said to be *apocarpous* (Fig. 280).

It must not be thought that in this family and its allies the sepals and the petals are always just five in number; for they may be more numerous and may become even indefinitely numerous, as in the water-lily. Other well-

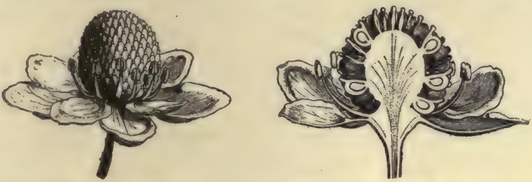

Fig. 280.—Apocarpous flower of a buttercup, showing the head of distinct carpels. —After Baillon.

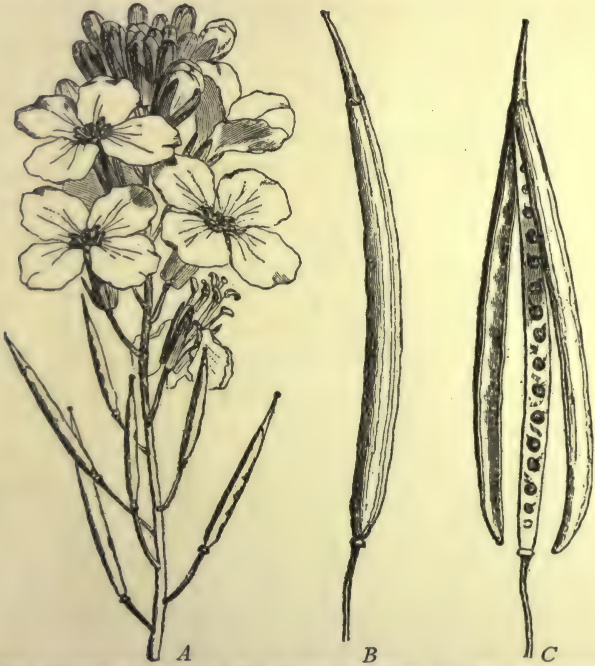

Fig. 281.—Flowers and pods of the Mustard Family: *A*, cluster of flowers and young pods; *B*, ripe pod; *C*, opening pod showing seeds attached to the false partition.—After Warming.

known representatives of the family are clematis, anemone, hepatica, marsh marigold, and peony (Fig. 207); and also the spurred larkspurs and columbines. Closely related to this family are a number of smaller ones, that share its general characters, and that contain such familiar plants as May-apple, water-lilies, barberry, bloodroot, poppies, etc.

Nearly related to the buttercups is a peculiar family, containing several well-known plants, and known as the Mustard Family (*Cruciferæ*). The flowers are peculiar in having four sepals in two sets, four petals in one set, six unequal stamens (two short and four long), and one carpel whose ovary is divided by a "false partition," giving to the pod (long or short) the appearance of being made up of two carpels (Fig. 281). Not only is the family to be recognized by this singular floral structure, but also by its more or less pungent taste, which reaches an extreme expression in commercial mustard, which is made by grinding to powder the seeds of certain species. Among the members of the family that are prized either for ornament or for use are stock, sweet alyssum, candytuft, wallflower, watercress, horseradish, mustard, cabbage, turnip, radish, etc.

165. **Roses.**—This family (*Rosaceæ*) is one of the best-known and most useful families of the temperate regions. Many of the flowers have a structure that suggests that of the buttercups, but the family is so extremely varied in this respect that no general description can include them all. In addition to such beautiful ornamental forms as the roses, the family contains a remarkable collection of valuable fruits. These fruits may be considered under three heads:

(1) BERRIES.—It so happens that none of these are true berries, but their real nature has been explained (§ 143).

Strawberries are so hardy that they may be grown in almost any part of America, from Alaska to Florida (Fig. 234). The common cultivated varieties have been derived from a wild species native along the Pacific Coast of America and introduced into cultivation from Chili about two centuries ago. The real cultivation of strawberries in the United States, however, began about sixty years ago, but did not reach large proportions until after the Civil War. Since that time the growth of the industry has been marvelous, thousands of varieties having been developed and tested. By means of refrigerator transportation strawberries begin to come north, from extensive plantations in the Gulf States, in February; and later, areas farther north supply the demand until 46° north latitude is reached.

The plants propagate by runners (§ 23), which are put forth after blooming and strike root; and the new plants thus started, either transplanted or allowed to remain, bear the next year. These runner-propagated plants are set out either in the spring or in late summer, and are protected through the winter by spreading upon them straw (mulching). The very common wild strawberry does not seem to lend itself to improvement.

Raspberries are grown more extensively in the northeastern United States than elsewhere (Fig. 233). The ordinary red and black varieties have been derived from native American plants, which are more hardy than those that have been introduced. The red raspberry is especially difficult to ship, and therefore the black raspberry is much more valuable commercially. A peculiar propagating habit of raspberries is taken advantage of in their cultivation. In the wild forms, late in the season, the tips of the bending stems (canes) take root and give rise to new plants; in cultivation this putting down of the tips is done artificially.

Blackberries belong to the same genus (*Rubus*) as the raspberries, and have only recently become prominent as cultivated fruits, although in their wild state they have been known and prized from the earliest times. Since the finer cultivated varieties have been introduced, blackberry culture has developed rapidly in importance, and is suited to almost all soils.

(2) STONE-FRUITS.—These valuable fruits are usually regarded as belonging to a single genus (*Prunus*). The peculiar ripening of the ovary into fleshy and stony layers has been explained (§ 143) (Fig. 232).

Peaches originated in China, where they have been cultivated from remote times, and came to Europe by way of Persia (hence the name *Prunus Persica*), and from Europe to America. The beautiful flowers usually appear very early in spring, and hence they are always in danger of late frosts. On this account peach culture is attended with great risk, and only those regions are favorable in which blooming is likely to be held back and late frosts are rare. Curiously enough, these risks are greater in the South than in the North. It follows that the great commercial supply comes from only a few regions. One of these is the Great Lakes region, the prominent areas being in New York and Canada along the southeastern part of Lake Ontario, along the southern shore of Lake Erie, and on the eastern shore of Lake Michigan (the Michigan "fruit belt"); a second great region extends from the shores of Long Island Sound to the Chesapeake Bay region; a third is northern Georgia and Alabama; a fourth extends from southern Illinois across Missouri into Kansas; and a fifth is almost the whole of California that is not mountainous. Perhaps the best-known peach-growing States are Maryland, Delaware, Georgia, Michigan, and California. In a popular way peaches are grouped as clingstones and freestones; but there are intermediate forms, and the same variety may be clingstone one season and freestone the next. Certain smooth-skinned varieties are called *nectarines*.

Apricots are intermediate between peaches and plums, resembling a smooth peach (nectarine) in external appearance, and having the smooth stone of a plum. They also originated in China or Japan, and the dangers in cultivation are the same as those of the peach. The apricot has never developed commercial importance in the eastern United States except in a few places, notably in New York. In California, however, it is one of the most important commercial fruits of the State, having been introduced into it by the Mission Fathers.

Plums are of so many kinds that they can hardly be spoken of all together. The numerous varieties have been derived from at least three species, one European, one Japanese, and one native. The most extensively grown and commercially important plums are from the European stock; and the two great areas of cultivation are California, and the Northeastern States north of Pennsylvania and west to the Great Lakes. In California the *prune* industry has been extensively developed, a prune being simply a plum that has dried sweet (without fermentation) without removing the stone (pit).

Cherries are of several varieties, derived from two European species. In general they are classified as sour cherries, which are largely grown in the eastern United States, especially western New York, for canning; and sweet cherries, which are most extensively cultivated on the Pacific Coast. There are a number of native species in the United States, and among them the black cherry furnishes a timber much valued on account of its beauty when polished.

(3) POME-FRUITS.—The peculiar character of this type of fruit has been explained (§ 143) (Fig. 235), and the name has been used in that of fruit culture in general, which is called *pomology*. The following forms all belong to the genus *Pirus*.

Apples have been cultivated from the most ancient times; and the thousands of varieties have all come from two wild species native to southwestern Asia and adjacent Europe, one giving rise to the common apples, the other to the crab-apples. This is the most important fruit of the temperate regions, and North America is the greatest apple-growing region of the world. For commercial purposes there must be a combination of such features as productiveness, quality, and long-keeping; and the best region of the country to produce all these extends from Nova Scotia to Lake Michigan. Other important commercial regions are Virginia, the Plains, Arkansas and the Ozarks, and the foothills of the Pacific Coast. Each year these regions produce about one hundred million barrels of apples. When first introduced into this country, the apple was prized chiefly for the manufacture of cider and vinegar; but it is used now more extensively than any other fruit as a fresh and evapo-

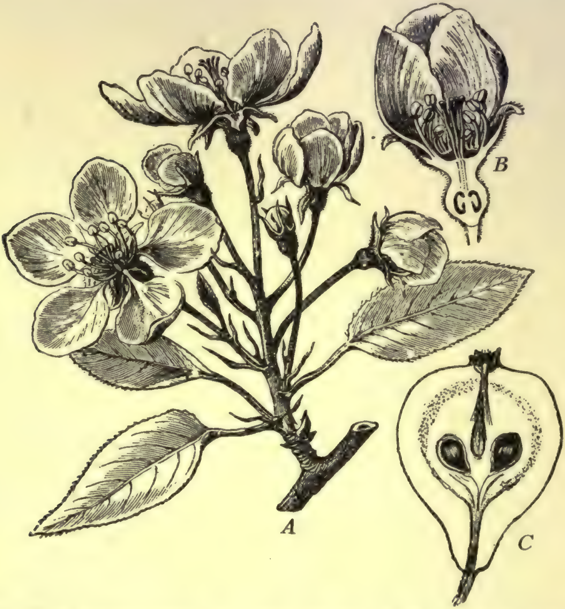

FIG. 282.—The common pear: *A*, flower cluster; *B*, section of a single flower; *C*, section of a fruit (core indicated by dotted outline).—After WOSSIDLO.

rated fruit. Apples are usually propagated by budding and grafting (§ 24) the desired variety on hardy young trees.

Pears are chiefly derived from a single European species and were introduced into this country by the earliest settlers (Fig. 282). Their most successful cultivation is in the Northeastern States (from New England to the Great Lakes) and on the Pacific Coast. In the central States extensive pear culture is attended with great risk on account of a dangerous disease known as pear-blight or fire-blight, the leaves turning brown or black as if scorched. This is one of the bacterial diseases (§ 77). Unlike most fruits, pears are very much improved when picked green and ripened indoors.

Quinces are well known, but have not been developed in variety or in commercial importance as have apples and pears, this probably being due chiefly to the fact that they cannot be eaten raw. The most important quince orchards in the United States are in western New York.

166. **Legumes.**—This is by far the greatest family (*Leguminosæ*) of the Archichlamydeæ, and is chiefly distinguished by its very irregular flowers and its pods, which are derived from a single carpel and become more or less elongated and sometimes remarkably conspicuous (Fig. 283). It is the peculiar pods (legumes) that have given name to the family. The ordinary flowers, represented by the sweet pea, were thought to resemble a butterfly, and hence were said to be *papilionaceous.* The upper petal (*standard*) is the largest, and erect or spreading; the two lateral petals (*wings*) are oblique and descending; while the two lower petals are coherent by their lower edges and form a projecting boat-shaped body (*keel*), which encloses the stamens and pistil. The relation of this structure to pollination by insects has been described (§ 147). This family, in its irregular flowers adapted to insect-pollination, holds the same position among Archichlamydeæ that the orchids do among Monocotyledons.

In so vast a family it will be impossible to enumerate all the forms that are well known on account of their common occurrence or usefulness, but some of them may be mentioned. The sweet pea, wistaria, and lupine suggest the numerous herbaceous forms with showy flowers. In this family also are found the numerous sensitive plants (§ 17) characteristic of southwestern arid regions (Fig. 284). Among the trees the following may be mentioned: common locust, prized for both its showy flowers and its valuable timber; honey locust, beset with conspicuous thorns (Fig. 60); redbud, with numerous pink flowers appearing upon the naked branches in early spring; and the singular coffee-tree.

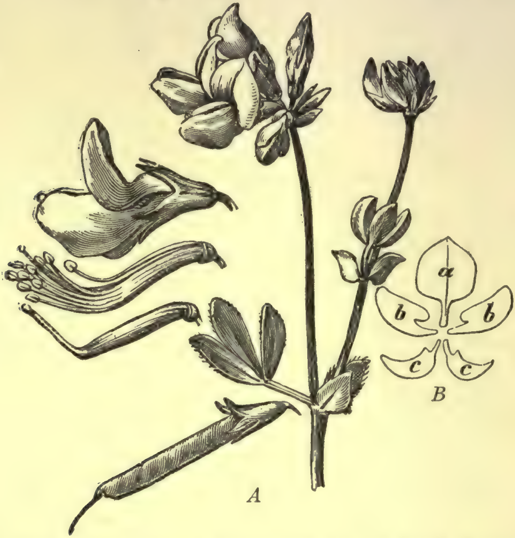

FIG. 283.—A leguminous plant: *A*, flowers and pods; *B*, petals separated to show standard (*a*), wings (*b*), and keel petals (*c*).—After WOSSIDLO.

Among the useful forms, the so-called forage plants are important; that is, plants used for pasturage or hay, just as are the grasses. The most common of these is *clover*, a genus (*Trifolium*) containing many species. The most important one to the farmer is the common red clover, affording valuable pasturage and clover hay, and also improving the soil (§ 77). The smaller white clover is also a very familiar plant associated with grasses in lawns, pastures, etc.; and its flowers are especially attractive to bees. *Alfalfa* (lucerne) is another important forage plant related to the clovers, and is especially valuable in the West where irrigation is employed. It is a native of western Asia, has long been cultivated in Europe, and was introduced into California about the middle of the last century. Since then it has become the most extensively grown forage plant in the arid regions of the Pacific and Rocky Mountain States.

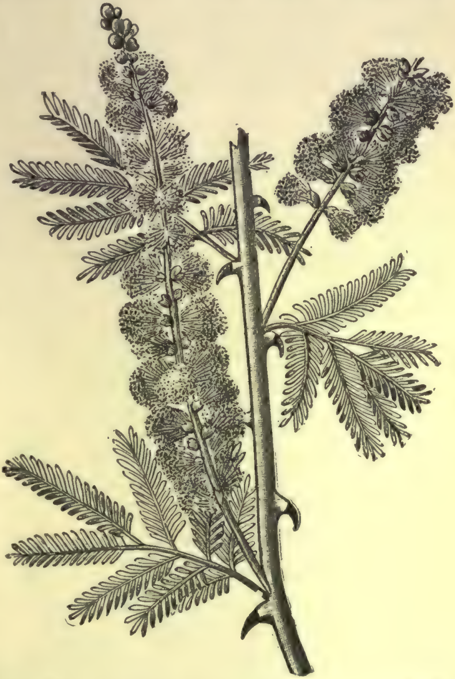

FIG. 284.—A sensitive plant, showing the inconspicuous flowers with numerous stamens, and the sensitive pinnately compound leaves.—After MEYER and SCHUMANN.

Besides the forage plants, the seeds of certain others are very familiar as food. The cultivated *peas* are natives of southern Europe and Asia, and have been cultivated for many centuries. They are distinguished as garden peas and field peas, the latter being rather a forage plant. The two types of garden peas are those with smooth seeds and those with wrinkled seeds, the former being earlier and hardier (hence most common in the market), the latter better in quality. *Beans* are of many kinds, but the common bean of Europe does not succeed well in the United States. Our common garden and field bean is the kidney bean, which reached the United States from South America by way of Europe. The lima bean is also of South American origin, and is most extensively grown in California. *Peanuts* (goobers) are curiously developed and very familiar pods. After the flower has fallen, its stem bends downward and pushes the young pod into the sandy soil, where it matures, and hence is sometimes called groundnut. Several of our native legumes also have this curious habit. The peanut is thought to be a native of Brazil, and is now grown in all warm regions of the world. In the United States it has become an important commercial crop of the Southern States since 1866, being chiefly grown in Virginia, North Carolina, Georgia, and Tennessee; the annual yield being four million bushels.

167. **Umbellifers.**—This is the highest family (*Umbelliferæ*) of the Archichlamydeæ, and the name has been suggested by the fact that the small flowers are massed in flat-topped clusters called umbels (§ 139) (Fig. 224). The family is distinguished also by the fact that the ovaries are inferior (§ 138). In general they are perennial herbs of north temperate regions. Parsnips and carrots are the thick tap-roots of two of the species, and celery is the blanched leaf-stalks of another. Some species are characterized by their aromatic foliage or fruit, as coriander, fennel, and caraway; and one species yields the deadly hemlock.

168. **Other useful Archichlamydeæ.**—Many well-known ornamental plants do not belong to the representative families described above, as violets, pinks, geraniums, nastur-

tiums, fuchsias, etc.; and some very useful plants also belong to scattered families. These latter may be grouped as follows:

(1) FIBERS.—The fiber plants are numerous, but there are three very conspicuous ones among the Archichlamydeæ.

Cotton.—The cotton plant is by far the most important fiber plant grown, being cultivated over a greater area and used for a larger number of purposes than any other fiber plant (Fig. 285). The cultivated varieties have originated from several tropical species, but in the United States the Sea Island cotton and the upland cotton are grown almost exclusively. The genus (*Gossypium*) belongs to the Mallow Family (*Malvaceæ*), to which the hollyhock and the hibiscus also belong, the most conspicuous peculiarity of the flower being the apparent coalescence of the numerous stamens into a central column (Fig. 214). The capsule (boll) of the cotton plant contains numerous seeds, which are covered with long hairs (lint) that are the cotton fibers (Fig. 285, *C*). At maturity the bolls burst, and the lint protrudes in a fluffy, cottony mass (Fig. 285, *B*). The cotton-gin was invented to separate the lint from the seeds, and the revolution it brought about in the cotton industry is well known.

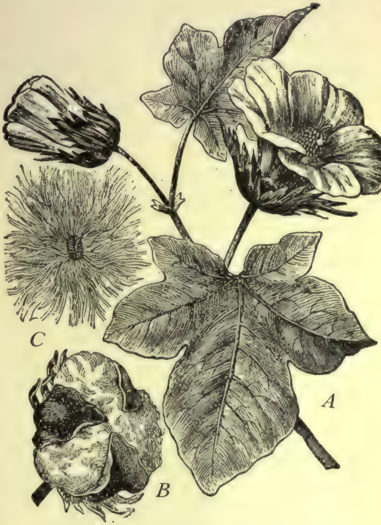

FIG. 285.—The cotton plant: *A*, flowering branch; *B*, fruit (boll) bursting; *C*, seed with fibers (lint).—After WOSSIDLO.

The Sea Island cotton, with its long and silky fibers, is the most valuable variety, reaching its greatest perfection along the coast region of South Carolina, Georgia, and Florida. The upland cotton is cultivated over a wider area, but is by no means of so fine a grade. In 1900, the greatest cotton-growing States, in the order of the number of acres under cultivation, were Texas, Georgia, Alabama, Mississippi, and South Carolina. There are valuable by-products from the cotton plant, the seeds yielding the well-known cotton-seed oil.

Flax.—The fiber of flax forms linen thread and cloth, and the extent of its use is second only to that of cotton. The species used is a small annual (*Linum*) native about the Mediterranean, and cultivated from the very earliest times (Fig. 286). The fibers are found in the stems, which are subjected to a series of processes for separating the fibers from the other parts. The oil yielded by the seeds is the well-known linseed oil, used in paints, varnishes, etc. Russia is the greatest flax-growing country in the world; but for excellence of fiber Belgium excels, where it is used in the manufacture of the famous Brussels lace. In the United States flax has been long cultivated in many States for its oil; but only recently has its cultivation for fiber attracted attention, and that chiefly in Michigan, Wisconsin, Minnesota, and Washington.

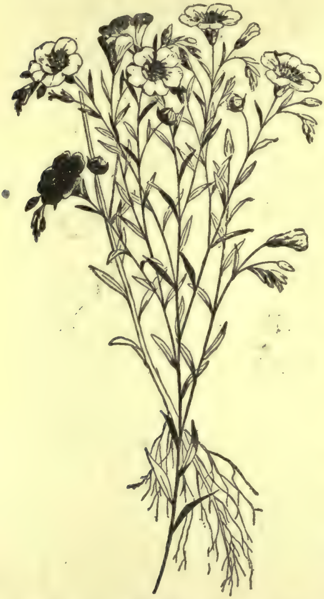

FIG. 286.—The flax plant.—After BAILLON.

Hemp.—This well-known fiber comes from an annual plant native to southern Asia, but long cultivated in Europe, and also naturalized in the United States (Fig. 287).

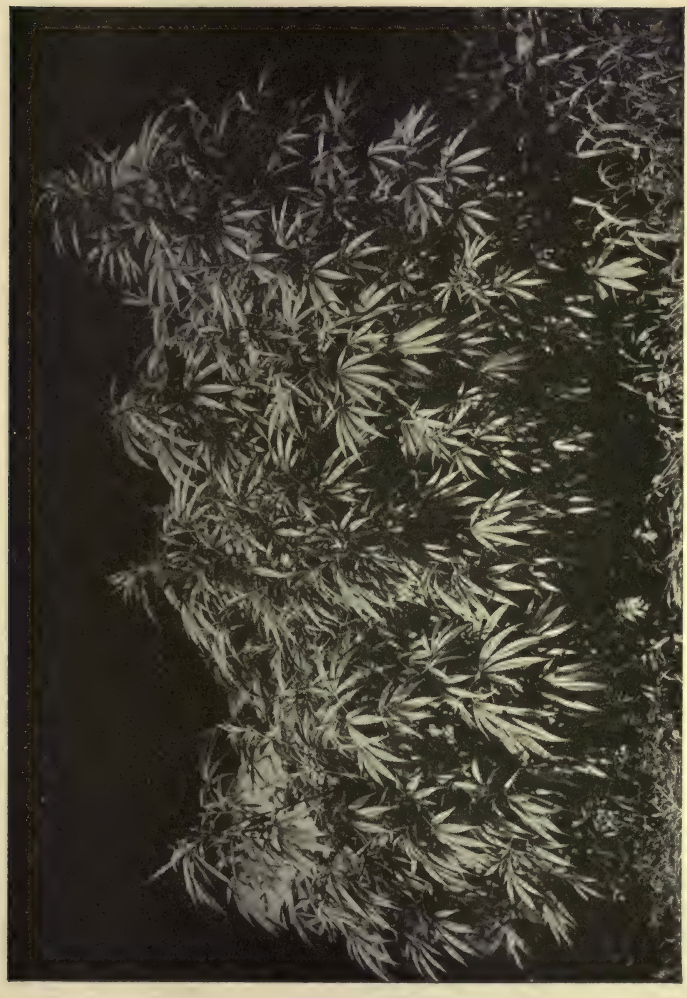

FIG. 287.—The common hemp plant.

It is a member of the Nettle Family (*Urticaceæ*). As in flax, the fibers used occur in the superficial region of the stem, outside the regular wood fibers. The most extensive cultivation of hemp is in European Russia; and it is somewhat cultivated in the United States, especially in Illinois, Missouri, and Kentucky. The name is applied also to any fiber that serves the same purposes as true hemp; for example, Manila hemp, which is obtained from a species of banana which is native in the Philippine Islands and extensively cultivated there.

(2) BERRIES.—The conspicuous berries not mentioned are the currants and the gooseberries, which are members of a small family (*Saxifragaceæ*) closely related to the Rose Family. These familiar plants belong to the same genus (*Ribes*) and are natives of the cool temperate regions. Therefore, their chief cultivation is in northern Europe and in the Northern United States and Canada. The ordinary varieties of white and red currants are well known and well cultivated in this country, but in no country has the gooseberry been developed to such size and quality as in England.

(3) GRAPES.—Grapes are true berries, but they are so important as to deserve separate mention. The genus is *Vitis*; and it gives name not only to the family (*Vitaceæ*), but also to the culture of grapes (*viticulture*). The cultivation of grapes for the manufacture of wine and raisins is as old as the history of man. The varieties cultivated in the Old World all belong to a single species (*Vitis vinifera*), which is now extensively grown in all countries bordering on the Mediterranean, and north to central Europe. This same European vine was introduced on the Pacific slope by the early missionaries; and now, excepting a few famous regions in Europe, California leads in the production of wine and raisins, having the largest vineyards in the world. In the northeastern States, however, native varieties have

been developed, more for what are called dessert purposes than for wine and raisins; and this culture has reached its highest perfection in New York, New Jersey, Maryland, Virginia, and Ohio. No cultivated plant is attacked by more diseases than the grape, nor have any plant diseases been more fully studied.

(4) CITROUS FRUITS.—These fruits all belong to a single genus (*Citrus*), whose species are shrubs or small trees, natives of tropical and subtropical Asia (China-India). The citrous fruits are numerous, but the three forms chiefly cultivated in the United States and common in markets are as follows:

Oranges are extensively cultivated in the United States in central and southern Florida, the delta region of the Mississippi, and California. All the varieties are derived from a single species (*Citrus Aurantium*), and may be grouped as bitter oranges and sweet oranges, the latter being the chief market form. The very popular seedless navel oranges of California were introduced in 1870 from Brazil by the United States Department of Agriculture, being a chance seedling variety.

A closely allied species (*Citrus nobilis*) produces the varieties of *mandarin* or kid-glove oranges. True mandarins are small and light orange in color, and are not so much prized in market as the dark orange or reddish forms known as *tangerines*.

Grape-fruits are extensively cultivated in Florida and California, all the varieties, most of which have originated in Florida, coming from *Citrus Decumana*, a native of the Malayan and Polynesian Islands. The original and best name for this fruit is *pomelo*, although it is sometimes called *shaddock* as well as grape-fruit. In reality, the pomelo or grape-fruit is the common round-fruited form of the markets, while the shaddock is a very different plant with a pear-shaped fruit.

Lemons also are cultivated in Florida and California; but they are not so hardy as the orange, and hence their cultivation is more restricted. The chief foreign supply comes from Italy, Spain, and Portugal. The lemon is a variety of the citron (*Citrus medica*); and another variety is the *lime*, which furnishes the commercial lime-juice.

(5) TEA.—The tea plant is a shrub native to subtropical Asia, and its dried leaves are one of the most important articles of commerce (Fig. 288). It has been cultivated in China and Japan for many centuries, and in the last century extensive plantations were established also in India, Java, and Ceylon. There are three distinct pickings in a season; some of the young leaves are picked in April for a fine quality of tea (young hyson) which cannot stand shipping to a distance; the ordinary picking for the general market begins in May; and later there is a third picking, which makes a low-grade tea. Different qualities and colors are produced by the different treatment of the same leaves, the numerous varieties being either green tea, in which the leaves are roasted quickly, or black tea, in which they are dried slowly until they are almost black. Outside of oriental nations the chief tea drinkers are the Russians, the British, and the Dutch.

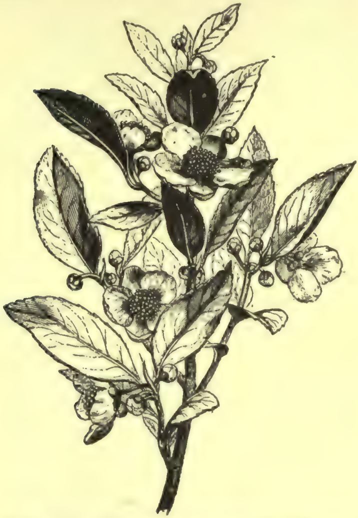

FIG. 288.—Flowering branch of the tea plant.—After BAILLON.

(6) CHOCOLATE.—Chocolate is obtained from the seeds of the cacao-tree, a native of Mexico, which was introduced into Europe by the Spaniards, and is now cultivated in all tropical countries. The fruit is about the size of a small cucumber and contains numerous large flat seeds embedded in its flesh. The seeds are crushed to a fine paste, which is heated and run into molds. Coco is obtained from chocolate by removing from it some of its oil.

CHAPTER XVIII

DICOTYLEDONS: SYMPETALÆ

169. **General characters.**—The Sympetalæ include the families of highest rank, about fifty in number, among which there are many well-known plants, and some of great use. The representative families are easily recognized, and five of them will be presented, with which a real acquaintance with the Sympetalæ may well begin.

170. **Heaths.**—In this family (*Ericaceæ*) there are often ten stamens, in two sets, so that there are five cycles of floral parts; and thus such forms are easy to distinguish from the following families, in whose flowers there are only four cycles. Heaths are usually woody plants, often shrubs, sometimes trailing, occasionally trees. One of the most peculiar and constant features of the family is that the anthers usually open at the top and generally by terminal pores (§ 134) (Fig. 213, *B* and *C*). The species belong chiefly to the cooler regions, often being the prominent vegetation in cold bogs and on heaths, to which latter they give name (Fig. 289).

Trailing arbutus, bearberry (kinnikinick), heather, rhododendron (Fig. 290), azalea, mountain laurel, wintergreen, and corpse-plant (Indian pipe) are familiar forms; while huckleberries, blueberries, and cranberries are staple fruits. The *cranberries* grow wild in mossy (sphagnum) bogs in the cool temperate regions of both America and Europe. Two kinds usually appear in market: the small cranberry, obtained from wild plants; and the large cranberry, extensively cultivated in several Northern States, especially in Massachusetts, New Jersey, and Wisconsin.

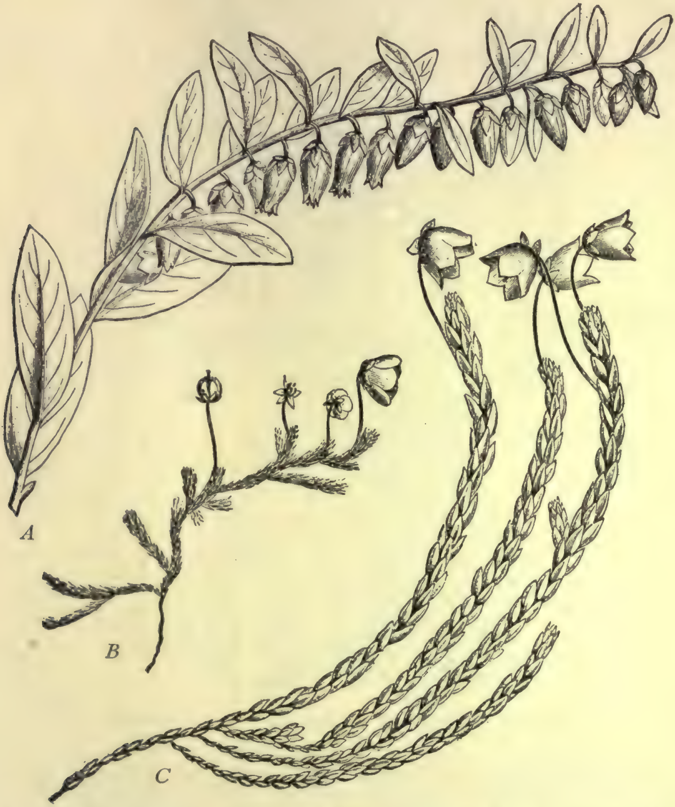

Fig. 289.—Heath plants: *A*, *Lyonia; B* and *C*, two species of *Cassiope*.—After Drude.

Huckleberries, a market name that includes blueberries, have not as yet been cultivated for commercial purposes, but are picked from wild plants, large areas of which are sometimes protected. In Maine, the protected "blueberry barrens" is said to include an area of about 150,000 acres.

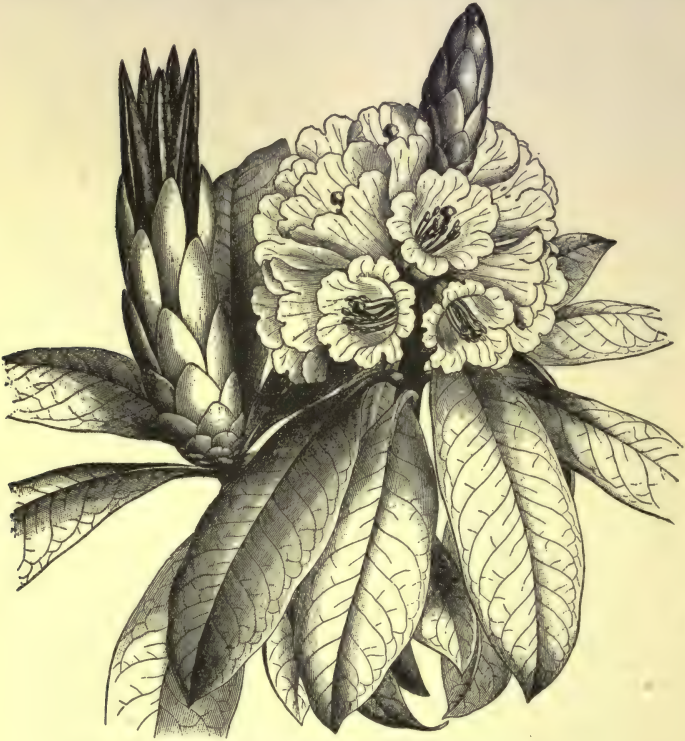

FIG. 290.—A flower-cluster of rhododendron.—After HOOKER.

171. **Nightshades.**—This great family (*Solanaceæ*) includes plants with more or less conspicuous and regular tubular corollas. The flowers have four cycles, a character which distinguishes this family from the former one; and regular corollas, a character which distinguishes it from the next one. Perhaps the most familiar illustration of the general type of flower is the morning-glory, which belongs to

a small related family. A very general feature of the nightshades is their rank-scented foliage, the leaves and

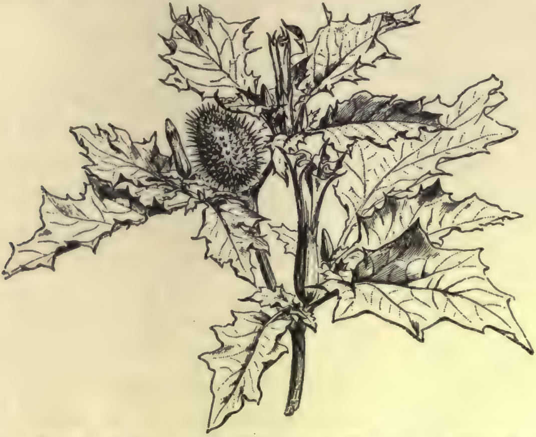

FIG. 291.—Branch of thorn-apple (Nightshade Family), showing flowers and fruit.—After BAILLON.

fruits of some of them being very poisonous. Among the familiar plants are capsicum (red pepper), ground cherry, belladonna, matrimony vine, henbane, petunia, and thorn-apple (jimson-weed) (Figs. 291 and 292); while the three following are of great commercial importance:

Potato.—This most common of all vegetables is often called Irish potato, because of its general use in Ireland; but it is a native of the mountainous region of America from southern Colorado to Chili. Like corn (maize), potatoes were found in cultivation by natives

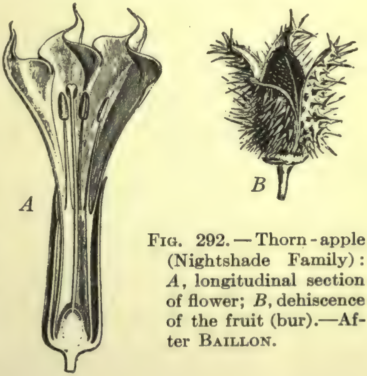

FIG. 292.—Thorn-apple (Nightshade Family): *A*, longitudinal section of flower; *B*, dehiscence of the fruit (bur).—After BAILLON.

upon the discovery of America, and were introduced into Europe by the Spanish conquerors, probably from Peru. For nearly two centuries, however, their importance was not appreciated; but now there are ten times as many bushels of potatoes produced in Europe as in the United States, the entire European crop being said to aggregate more bushels than the entire wheat crop of the world. New York is our great potato-producing State. There are hundreds of varieties, new ones replacing old ones every year; but they are all derived from a single species (*Solanum tuberosum*). It should be remembered that these tubers are subterranean stems (§ 27) enlarged as depositories of starch, the stem structure being indicated superficially by the eyes (bracts with axillary buds). In planting, the tubers are cut in pieces, each piece containing one or two eyes and as much of the food-supply as possible.

Tomato.—The tomato was once called love-apple, and was thought to be poisonous. It is grown more extensively in North America than elsewhere; and in the United States there is no vegetable so extensively grown for canning, about 300,000 acres being required to produce the annual crop. The principal tomato-growing States are Maryland, New Jersey, Indiana, and California. The numerous kinds vary in form and color, all coming from a single species (*Lycopersicum esculentum*), which is native to the Andean region of South America.

Tobacco.—It is well-known that the Indians used tobacco long before the discovery of America, but never excessively (Fig. 208). From America its use was introduced into Europe, gradually extending to the Asiatic nations, until now the Turks and Persians are the greatest smokers in the world. In the United States tobacco culture began in Virginia, at the first settlement of the colony; and it became the leading industry also of Maryland, North Carolina, South Carolina, Georgia, and Kentucky at their first settlement. To-day Florida, Connecticut, Pennsylvania, and Wisconsin lead in the production of the finer grades; while the States producing the other grades are, in their order, Kentucky, Virginia, North Carolina, Maryland, Ohio, Indiana, and Missouri. The finest tobacco in the world is grown in Cuba, that from Florida ranking second; while the tobacco of Borneo, Ceylon, and the Philippine Islands is not much inferior. The growing plant is handsome, with showy flowers, and is often used as an ornamental plant. The single species is *Nicotiana Tabacum*, and is of South American origin.

172. **Labiates.**—This family (*Labiatæ*) has received its name from its two-lipped or bilabiate corolla (§ 133). This does not mean that all plants with bilabiate flowers belong to this family; but if this character is associated with square stems and opposite leaves, and also with an ovary so deeply lobed that it looks like four little nutlets in the bottom of the flower, the plant can be regarded as a member of the family (Fig. 293). The foliage is usually aromatic, and the family is commonly called the Mint Family. Many common wild plants and garden herbs will be recognized as belonging here, familiar names being sweet basil, pennyroyal, lavender, mint, hoarhound, hyssop, savory, marjoram, thyme, balm, sage, rosemary, catnip (Fig. 293), etc.

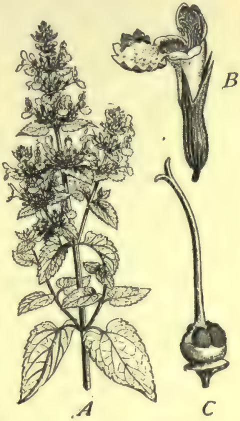

FIG. 293.—Catnip (Mint Family): *A*, flower-cluster; *B*, single flower; *C*, pistil, showing the deeply four-lobed ovary.—After BAILLON.

173. **Madders.**—This very large tropical family (*Rubiaceæ*) is represented in our flora by only a few forms, such as bluets, buttonbush, partridgeberry, etc., which may be

recognized generally by the regular tubular corolla, the inferior ovary, and the floral number four. However, the tropical members of the family yield two important products that should not escape mention.

Coffee.—The coffee plant (*Coffea arabica*) is a native of Arabia and Abyssinia, and is a slender tree becoming fifteen to twenty-five feet high (Fig. 294), but rarely allowed to become more than half that height in cultivation. The fruit is a dark scarlet berry (Fig. 295) containing two horn-like seeds, which are ordinarily called coffee-beans (Fig. 296). The use of coffee can be traced back in Arabia for only about five hundred years, and its use in Europe extends over only half that time. Coffee plantations have been established in regions of high annual temperature (ranging from 60° to 90°), Brazil producing more coffee than all other coun-

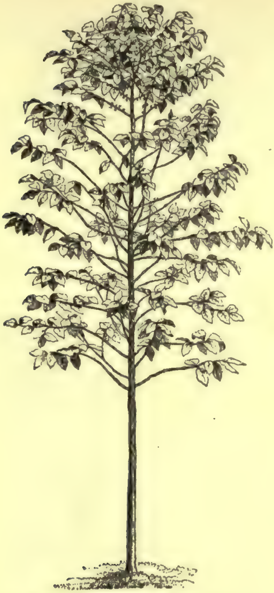

Fig. 294.—The coffee-tree. After Baillon.

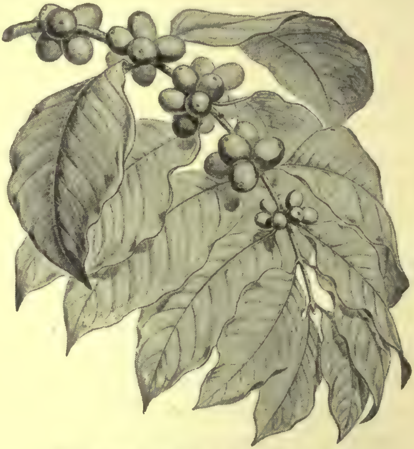

Fig. 295.—Fruiting branch of coffee. After Baillon.

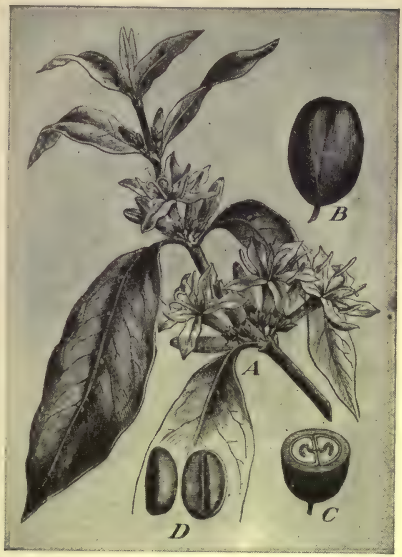

FIG. 296.—Coffee-plant: *A*, flowering branch; *B*, berry; *C*, section of berry; *D*, seeds (coffee-beans).—After WOSSIDLO.

tries combined. Other prominent coffee-growing countries are Mexico, Central America, Java, Sumatra, India, Ceylon, Arabia, Hawaiian Islands, and the West Indies. Of the many thousand tons shipped from these countries, the United States consumes nearly one-half, averaging over nine pounds a year for each inhabitant. Mocha coffee comes from Arabia, while the sources of the other kinds are usually indicated by the names.

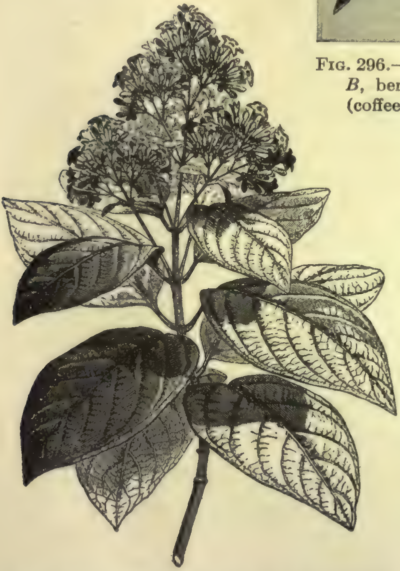

FIG. 297.—Flowering branch of a cinchona plant.—After BAILLON.

Cinchona. — This is the name of a genus containing numerous species of trees that grow in South America, chiefly along the eastern slopes of the western mountains (Fig. 297). The bark yields the well-known quinine, as well as other alkaloids, and is commonly called Peruvian bark. It is stripped from the trees by the Indians and carefully dried. Although the trees are becoming more scarce every year, no attempt has been made to cultivate them where they are native; but in Java, British India, Ceylon, Japan, and Jamaica there are extensive plantations of cinchona.

174. **Composites.**—This is the highest family (*Compositæ*) of Dicotyledons, and contains the most numerous species. Composites are found everywhere, but are most numerous in temperate regions, where they are usually herbs.

The name of the family suggests the most conspicuous feature; namely, the organization of the numerous small flowers into a compact head which resembles a single flower, formerly called a compound flower. So common are the Composites that the general structure of the head should be understood. Taking the head of *Arnica* as a type (Fig. 298, *A*), the outermost set of organs consists of more or less leaf-like bracts or scales (*involucre*), which resemble sepals (not seen in figure); within these there is a circle of flowers with conspicuous yellow corollas (*rays*), which are split above the tubular base and flattened into a strap-shaped body (Fig. 298, *B*), and much resembling petals; within the ray-flowers is the broad expanse called the *disk*, which is closely packed with very numerous small tubular flowers known as *disk-flowers*. If a disk-flower be removed, it will be discovered that the ovary is inferior, and that arising from it, around the tubular corolla, there is a tuft of delicate hairs (*pappus*) which represent the sepals (Fig. 298, *C*). This pappus surmounting the akene (§ 143) in Composites may be lacking; it may be a tuft of hairs, as in *Arnica*, thistle, and dandelion; it may be a cup or a set of scales; or it may develop grappling appendages, as in Spanish needles (Fig. 257) and beggar-ticks (Fig. 258). Most of the heads of composites have the general structure described for *Arnica;* but in the dandelion and its allies the disk-flowers are like the ray-flowers, with conspicuous strap-shaped corollas (Fig. 299).

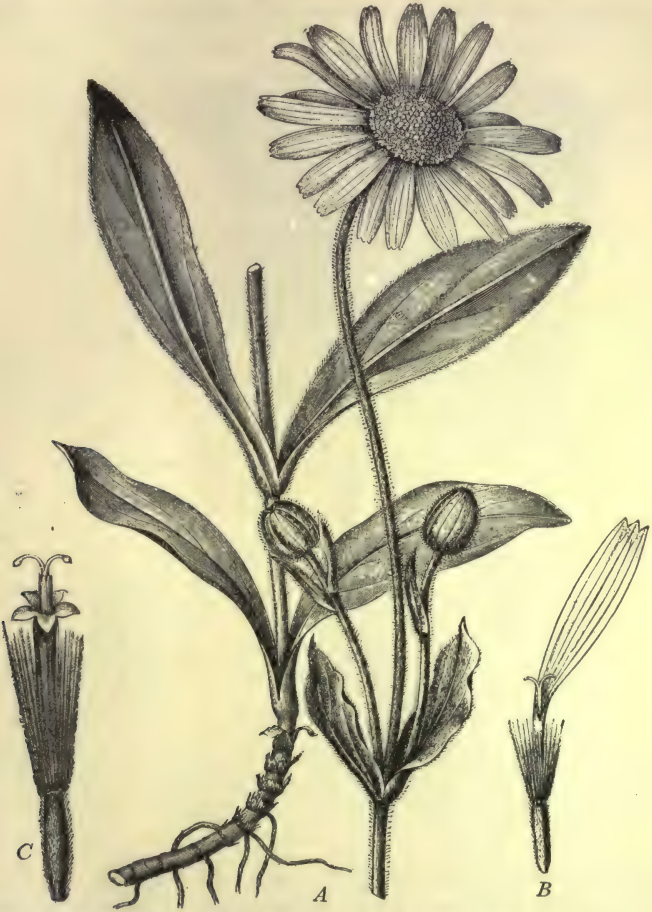

Fig. 298.—*Arnica: A*, plant bearing an open head, showing the conspicuous rays and disk; *B*, ray-flower; *C*, disk-flower.—After Hoffman.

Some of the well-known forms, either wild or in cultivation, are ironweed, ageratum, blazing star, goldenrod, daisy, aster, everlasting, rosinweed (compass plant), ragweed, cockle-bur, zinnia, sunflower, dahlia, cosmos, marigold, chrysanthemum, tansy, sage-brush, burdock, thistle, and dandelion. The only plant extensively used for food is lettuce.

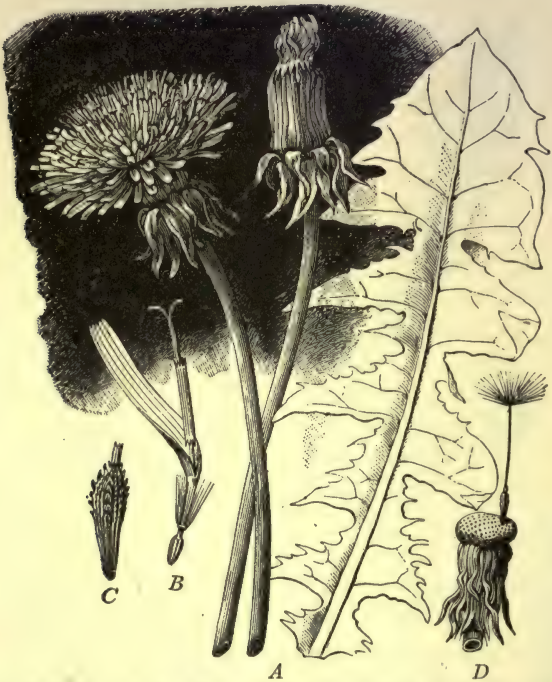

Fig. 299.—Dandelion: *A*, two flower-stalks, one head being closed and showing the double involucre, the other open and showing all the corollas strap-shaped; *B*, single flower; *C*, akene; *D*, receptacle, with single pappus-bearing akene.—After Strasburger.

175. **Other useful Sympetalæ.**—Some well-known plants that are not included in the families given above, but that

should be recognized as Sympetalæ, are honeysuckle, elder, lobelia, bluebell, primrose, morning-glory, lilac, milkweed, gentian, phlox, mullein, snapdragon, and verbena. Some additional prominently useful plants are as follows:

Sweet potato belongs to the same genus (*Ipomœa*) as the morning-glory, having long trailing stems and clusters of the well-known large oblong or elongated roots. It is not known whether it is native to the East Indies or America, but it is extensively cultivated in all warm countries. In the United States the cultivation of the sweet potato as a commercial crop is confined almost exclusively to the Southern States, but important areas are found also in New Jersey, Ohio, Indiana, and Illinois. The varieties called yams in the South are all sweet potatoes, and the name really belongs to a very different plant.

Olive.—The olive-tree has been known and cultivated from the most ancient times, and has entered largely into the life and customs of Mediterranean peoples (Fig. 300). It is thought to be a native of southern Europe and Asia Minor, and thrives best in dry climates such as those of Syria and Assyria. It is cultivated also at the Cape of Good Hope, in Australia, and in California. It is a very long-lived tree, a thousand years having been

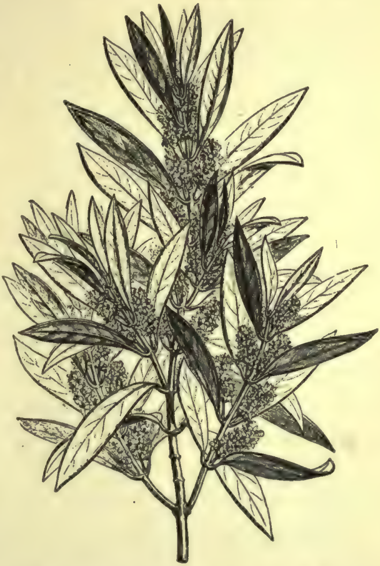

FIG. 300.—Flowering branch of olive. After BAILLON.

reported for some individuals. The oil obtained from the fruit is in as common use in Mediterranean countries as butter and lard in the United States. The products that reach this country are olive-oil and pickled olives; but dried olives also are much used in certain olive-growing regions.

GOURD FRUITS.—The tropical and subtropical family (*Cucurbitaceæ*) that is popularly called the Gourd Family contains numerous forms that are used by tropical peoples not only as food, but also in the manufacture of various utensils. The fruit is characterized by its very large size and hard rind, and the flesh within is often edible. The best-known edible forms in the United States are as follows:

Watermelon is a native of tropical Africa, and has been cultivated from the most ancient times. There is no country where watermelon culture is conducted on so extensive a scale as in the United States. The chief commercial supply comes from the Southern States, the so-called Georgia watermelon being the best-known variety; but a very large melon industry has been developed also in Colorado.

Muskmelons all belong to a single species (*Cucumis Melo*), which is native to the warmer parts of Asia, but is now cultivated all over the world. It is said that one-half of the muskmelon crop is grown in New Jersey; but in the western markets Michigan and Colorado are very important centers. The two general types of muskmelons are the furrowed type, with hard rinds, known as *cantaloupes;* and the netted type, with softer rinds, known as *nutmeg melons.* Two important varieties of nutmeg melons have been developed recently: the Osage melon, from southwestern Michigan; and the Rocky Ford melon, from Colorado.

Cucumbers belong to the same genus as muskmelons, and are derived from a species (*Cucumis sativus*) native to southern Asia. They are grown in all parts of the United States, and their extensive use as pickles, etc., is well known.

Pumpkins were cultivated by the Indians in their fields of maize, as they are now, and are probably of tropical American origin, although no wild plants are known. Some *squashes* belong to the same species (*Cucurbita Pepo*), but others are of Asiatic origin.

CHAPTER XIX

PLANT-BREEDING

176. **Definition.**—The purpose of *plant-breeding* is to improve cultivated plants, just as the purpose of *animal-breeding* is to improve domesticated animals. Great progress has been made in the science of plant-breeding, so that it is possible now in many cases to breed for certain desired improvements with great confidence that they will be secured. The skilful plant-breeder not only must know how to make plants grow, but he must know also the laws connected with the reproduction of plants.

177. **Variation.**—The fact with which the plant-breeder starts is that plants tend to vary. If all the seeds from one parent plant are sown, the plants that come from them will all resemble the parent in a general way; this handing down of similarities from one generation to the next is called *heredity*. But while there is this general resemblance to the parent, there are variations, one or more of the new plants perhaps resembling the parent less than the others do. It is this fact that makes plant-breeding possible; and instead of relying upon nature to present to him all the variations he needs, the plant-breeder by changing conditions increases the tendency of plants to vary, and also by crossing multiplies variations. The important thing is to obtain as many and as wide variations as possible.

178. **Vegetative propagation.**—If among varying plants there appears one that is desirable, it may be possible to propagate it vegetatively, that is, without using the seed.

Such propagation is much more certain, for propagation by seed introduces variations. Some plants are propagated naturally in this way, as those with thickened underground shoots (rootstocks, tubers, bulbs) or with runners (strawberry, etc.).

Others are propagated by artificial methods. For example, *cuttings*, often called slips, are pieces of the plant that are found to be able to grow when put in the soil, as of geraniums, grape-vines, etc. Even leaves may be used as cuttings, as in the begonia; and cuttings of the potato tuber are used in its propagation. *Grafts* are cuttings inserted in plants (§ 24) (Fig. 55), and it is common for the plant in which a graft is inserted (*stock*) to differ from the plant that is being grafted on it, securing among other things greater hardiness and a saving of time; for example, it is common to graft pears on quince stock. *Budding* is a variety of grafting in which only buds from the desired variety are grafted upon stocks. Grafting and budding are very common in the cultivation of tree fruits. *Layering* consists in bending down a stem to the ground and covering it for a short distance with soil; when roots strike into the soil from a covered joint, the connection with the parent plant is cut, and a new plant is thus obtained (§ 23). This process is common with such plants as gooseberries, blackberries, etc., and resembles in a general way the natural method of propagation by runners.

179. **Crossing.**—The artificial production of hybrids (§ 149) is used extensively to secure new varieties which may be desirable. The process consists in removing the young stamens from the flower to be operated upon; at the proper time placing upon the stigma pollen from the desired plant, and covering the flower or flower-cluster thus pollinated with a gauze or paper bag to prevent the approach of any other pollen. The seeds thus obtained are carefully collected and planted, and the new plants observed.

Among them there may be found one or more with a desired variation, or at least the beginnings of it. These plants are preserved and the others destroyed. Often many thousands of young plants are thus started, and most of them destroyed.

180. **Selection.**—When a desired variation has appeared, the work of improving and establishing it must follow. This is done by means of *selection,* and it involves great care and patience. The selected plants are carefully guarded, no foreign pollen being allowed access to their flowers. Their seeds are planted, and among the new plants that come up those showing the desired variation are preserved and the others are destroyed. This selection goes on generation after generation until only the desired variety is produced. It is then said to be established, and can usually be depended upon to produce its kind.

Even after a variety has thus been established, great care must be used in selecting from the best plants seeds for planting, or the variety will "run down." It is a great mistake to suppose that seeds from inferior plants will do just as well for sowing as seeds from the best plants. Farmers have learned this in selecting their seed-corn, seed-wheat, etc.; and their success depends upon their wise selection of the seeds to plant. It is important to know that in this selection of seed the character of the individual plant that produces it is the important thing. To select for planting the largest ears of corn from a pile of corn does not result so well as to select in the field the plants that produce on the average the best ears.

The process of selection is being applied also in the development of varieties that resist certain diseases. For example, in a field that has been ravaged by some disease a few plants may be found that have resisted the attack successfully. This means that the variation in these plants is a very desirable disease-resisting power. Starting with these plants, therefore, selection may be able to develop a race remarkably free from this particular disease. This method of combating disease may sometimes prove more effective than any attempt to save the plants that are subject to it.

The story of the development of the best-known varieties of cultivated plants is a very interesting one, telling how promising varieties have been discovered, and with what wonderful patience they have been developed into usefulness. The recent great increase in knowledge of the principles of plant-breeding has made the development of desirable varieties more definite and rapid than it has ever been before.

CHAPTER XX

FORESTRY

181. **Definition.**—The term *forestry* is difficult to define, for it includes much more than is usually supposed. In general, it is the management of forests, so that they may serve their purpose; but the purpose of a forest includes many things. Forestry does not deal with individual trees, but with an assemblage of trees; perhaps it would be best defined as the *management of woodland.* There are two prominent aspects of forestry. Forests furnish wood crops, as wheat-fields furnish wheat crops; and from this standpoint forestry resembles agriculture. But forests also hold important relations to climate, water-supply, etc.; and from this standpoint they are to be considered as features of the earth's surface.

182. **History of forestry.**—The history of forestry in every country has been the same. At the first settling of a country by civilized people, the forests were looked upon as impediments to agriculture, and the clearing of the forest was a part of pioneer work. As forests cover most of the best land, this pioneer clearing was necessary. After agriculture became established, forests ceased to be regarded as impediments, and came to be prized as the source of timber supply. They were wastefully ravaged for this purpose, the best trees being culled out, countless young ones destroyed, and fires completing the reckless waste. European countries passed through this stage many years ago, and the United States is just emerging from it. When

this wasteful use of forests has proceeded so far that the disastrous consequences are in plain sight, the forestry stage begins, and the proper management of forests is established. In European countries forestry has been long established and has become highly developed, especially in Germany and France. In the United States the Government has established a Bureau of Forestry, and certain States have adopted a definite forest policy.

183. **Supply forests.**—This name has been suggested for those forests used primarily as a source of wood-supply. The crop of wood differs from ordinary crops in that it is natural growth and needs a long period to mature. The problem is to obtain as much wood from the forest as possible year after year, without diminishing its productiveness; in other words, to use it and preserve it at the same time. There is a best time for cutting, that is, harvesting, in the life of each kind of tree, a time determined by its size and the quality of its wood. The forest habit—the growing of trees close together—secures the lofty symmetrical trunk, with branches carried high, the most favorable form for use. Trees that are "ripe" not only can but should be removed, that the younger ones may come to vigorous maturity. In this way a continuous succession of suitable trees becomes ready for removal, and every tree in the forest is given an opportunity to do its best. The thoughtless cutting of trees usually secures one good crop from a forest; while a forest managed by a forester yields a succession of good crops.

When the forester takes charge of a forest that has had no management, he first removes the undesirable trees; but the lumberman would remove the most desirable. The forester knows, however, that in this way the quality of the remaining trees will be improved, and in the long run he will get a larger and better crop. The cutting is so arranged that the openings left will give opportunity for seedlings to develop; so that in a forest properly managed there are trees in every stage of development, from seedlings to those ready to be cut. Such management is being adopted not only in large forests that are prominent sources of wood-supply, but also on individual farms, where the wood-lot is as carefully managed as the grain-field. Detailed plans for such management can now be obtained from the Bureau of Forestry or from State foresters, so that ignorance is no longer any excuse for mismanagement.

184. **Protective forests.**—This name has been suggested for those forests that are used primarily as a soil cover. Such forests are used also as supply forests, but their chief purpose is to cover the soil. Forests are great regulators of water-flow, retaining the water of rains and letting it pass gradually into the streams. When they are removed, streams that formerly contained a steady supply of water are subject to alternations of flood and extremely low water. When forests are removed from water-sheds and the head-waters of rivers, this result becomes disastrous. The head-waters of prominent rivers are generally in mountainous regions; and the removal of forests there results not only in flooded rivers, but also in slopes stripped of their soil and deeply gullied. In such regions, therefore, the forest both regulates the water-flow and protects the soil.

In consequence of these facts, the Government has set apart certain forest areas upon the head-waters of the principal rivers as forest reservations. These reservations are guarded from fire and from ruthless cutting, but are cut for timber under proper forestry management. Especially are such reservations imperative in the West where irrigation is necessary, which must depend upon a steady supply of water from the mountains. On January 1, 1905, there were sixty-two such reservations in various parts of the West, including over sixty-three million acres. States also have established forest reservations, most prominent among which are New York and Pennsylvania; while Michigan, Minnesota, and other States are following their example.

185. **Reforestation.**—In many regions where forests have been removed completely, and on the treeless prairies and plains, trees must be started and a forest cover gradually developed. In European countries, where many hill slopes had been cleared of all trees and the soil gullied and washed away, reforestation has been conducted on a large scale. Many a hilly Oriental country, now barren, was once forest-clad and fertile, as Palestine, whose streams have disappeared, and Mesopotamia, once a garden watered by the Euphrates, but now a desert.

In the United States extensive reforestation is required only on the prairies and plains, where active measures are taken to stimulate tree-planting; and perhaps eventually some real forests may be developed in these treeless regions. It may be well to call attention to the fact that tree-planting, such as "Arbor Day" stimulates, is not forestry; and that the real problem of forestry in the United States to-day is the proper management of existing forests.

CHAPTER XXI

PLANT ASSOCIATIONS

186. **Definition.**—The earth's surface presents such diverse conditions for plant life that plants become grouped according to the conditions favorable for their growth. These groups of plants, living together in similar conditions, are called *plant associations*, or sometimes plant societies or plant communities. For example, a meadow is a plant association growing in conditions that favor certain grasses; a forest is an association growing where certain trees are favored, etc. In these associations grasses and trees are simply the conspicuous types; but numerous other plants, which the same conditions favor, are associated with them. Each plant association, therefore, indicates a special set of conditions for plant growth, and to discover these conditions is a very important kind of field work.

187. **Water.**—Water is probably the most important condition that determines plant associations. The available amount of water for plants varies in different areas, from the very small supply in deserts to the abundant supply in swamps and lakes. The character of the soil has a very important effect upon water-supply; for some soils retain water and others do not, so that what is called the water-level is of varying depths (§ 39). Not only are the amount of water and the depth of the water-level important, but also the substances that the water contains in solution, which may prevent certain plants from growing and permit others.

In any given area the amount of available water may not remain the same. For example, the margins of ponds may slowly encroach upon the open water; ponds may bebecome converted into bogs; and bogs into dry ground. In his drainage operations and removal of forests man has made changes in the water-supply over extensive areas. All of these changes involve the destruction of old plant associations and the coming in of new ones.

188. **Temperature.**—The temperature of the air and of the soil during the growing season is very important in determining the presence of different plants upon any area. For each kind of plant there is what may be called a zero temperature, below which it is not in the habit of working. The succession of plants during a single growing season illustrates the distribution of plants by temperature, spring plants being able to endure greater cold than can those of the summer. This distribution in time indicates the more important distribution in space that is brought about by differences in temperature.

Permanent changes in the temperature of a region, affecting the distribution of plant associations, are evident only in tracing the history of plants back into what are called geological times. At certain times arctic conditions prevailed in regions now temperate, and this had an immense influence on plant life.

Plant associations are not determined by one condition, but by a combination of conditions. The simplest illustration of this fact may be obtained by combining the water and the temperature conditions. For example, if there is a combination of scanty water with high temperature, a desert is the result; but if the combination is abundant water and high temperature, luxuriant vegetation is the result. Since the possible combinations of water-supply, temperature, and other conditions are endless, it is evident that there are very numerous plant associations.

189. **Light.**—All green plants cannot have an equal amount of light, and some have learned to live with a less amount than others. In a general way this difference is recognized in the terms *light-plants* and *shade-plants*, and it permits plants to grow in strata. For example, in a forest association the tall trees form the highest stratum; below this there may be a stratum of shrubs, then tall herbs, then low herbs, then mosses and lichens growing close to the ground. If a forest is cleared, the remaining plants of the association are very much affected; and if a forest encroaches upon another association it is sooner or later destroyed. The development of the vernal habit in connection with deciduous forests, which was described in § 27, is a means by which certain plants avoid the forest shade and secure the forest soil.

190. **Wind.**—In regions of strong and more or less continuous wind, as near the seacoast, around the Great Lakes, and on the prairies and plains, this condition has much effect upon the character of the plants. Wind is a great drying agent, and increases the loss of water from plants by transpiration (§ 15), so that plants exposed to it must be able to check transpiration.

191. **The great groups of associations.**—For convenience, the very numerous plant associations are grouped on the basis of their water-supply. Such a classification is not a natural one, for no single condition determines an association; but for general purposes it serves well to introduce the associations to observation. On this basis there are three great groups of associations, as follows:

(1) *Hydrophytes.*—The name means "water-plants," and applies to those associations with an abundant water-supply, growing in water or in very wet soil.

(2) *Xerophytes.*—The name means "drought plants," and applies to those associations with a scanty water-supply. True xerophytes are exposed to dry soil and air.

(3) *Mesophytes.*—Between the two extremes of the water-supply there is a great middle region of medium water-supply, and plants of these medium conditions are mesophytes ("medium plants"). It is evident that mesophytes pass gradually into hydrophytes on the one side and into xerophytes on the other.

CHAPTER XXII

HYDROPHYTES

192. **Adaptations.**—When a plant lives entirely or partially submerged in water, its structure differs in many ways from that of an ordinary land plant, and these adjustments to water life are called *adaptations*. On parts under water the epidermis is thin and permits absorption, so that in a completely submerged plant its whole surface absorbs. When this is the case, the root-system is much reduced in extent as compared with a land-plant of the same size, for it is not the only organ for water absorption. In submerged plants the rigid tissues are less developed than in land plants, for the buoyant power of water helps to support the plant. This fact may be illustrated by taking from the water submerged plants that seem to be upright, with all their parts spread out; upon removal they collapse, not being able to support themselves. Water-plants are also usually provided with air-chambers and passageways that the air may be free to reach the working cells.

A few of the most characteristic hydrophytic associations are given as illustrations, some of which occur in almost every neighborhood.

193. **Pondweed associations.**—Water-lilies and pondweeds are conspicuous members of these associations, the former with floating leaves (pads) (Fig. 301), the latter often entirely submerged. Associated with them are numerous other forms with floating or submerged leaves. The plants are anchored by their roots and rootstocks in

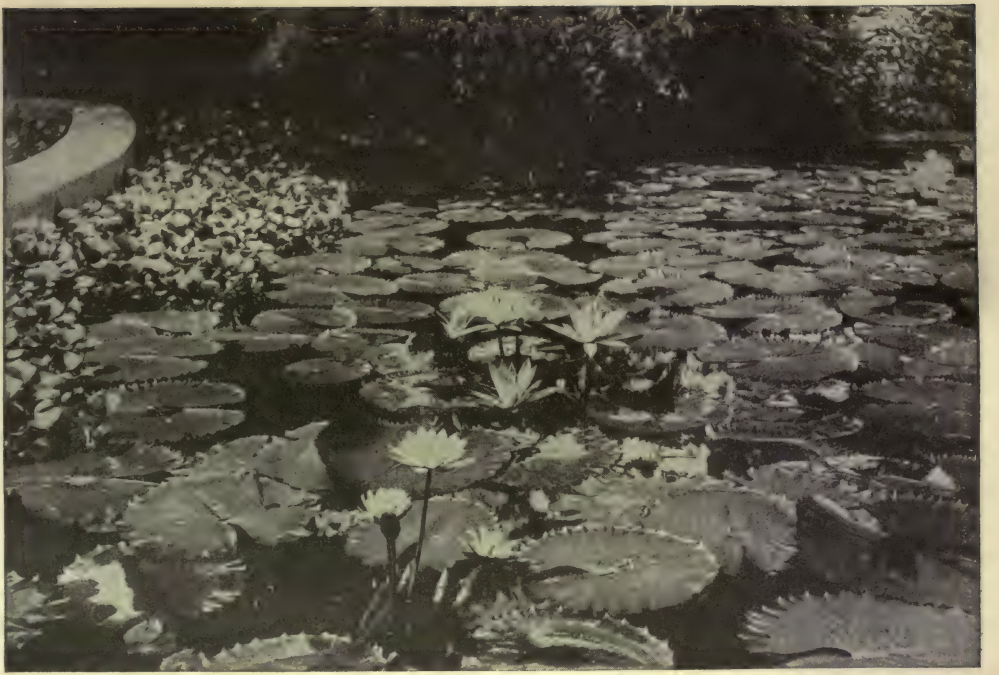

FIG. 301.—An artificial water-lily pond.

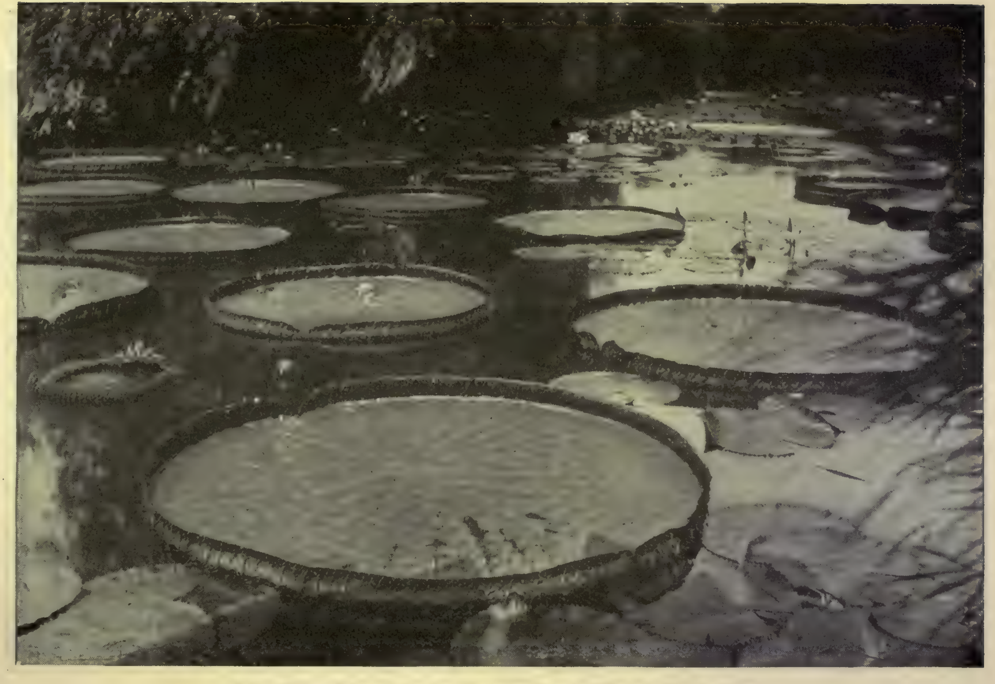

Fig. 302.—*Victoria regia*, the great water-lily of the Amazon.

the mucky bottom; and even when they do not send leaves up to the surface of the water, they usually send up the flowers that they may open in the air. In parks and greenhouses, the great water-lily of the Amazon (*Victoria regia*), the largest of all the water-lilies, is commonly seen (Fig. 302). Floating and submerged leaves are very different in form, and when both kinds occur on the same plant the contrast is striking (Fig. 303).

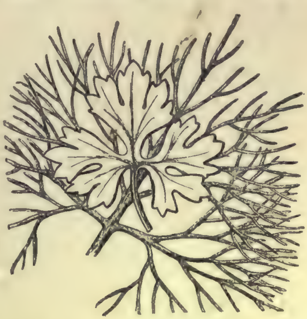

FIG. 303.—Submerged and aerial leaves of a water buttercup.—After STRASBURGER.

194. **Reed swamps.** — The reed-swamp plants are tall, wand-like forms that grow in the shallow margins of small lakes and ponds (Fig. 304). Prominent among them are cat-tails, bulrushes, and wild rice; and associated with these tall forms the arrowleaf is often found. This assemblage of plants forms the usual high fringe along swampy shores, and they have been called the pioneers of land vegetation; for their growth and the entangled detritus make the water more and more shallow, until finally the reed plants are compelled to migrate into deeper water. In this way small lakes and ponds may become converted first into ordinary swamps, and finally into wet meadows. Instances of nearly reclaimed ponds may be found, where bulrushes, cat-tails, and reed grasses still occupy certain wet spots, but are shut off from further migration.

195. **Swamps.**—Ordinary swamps are occupied by sedges and coarse grasses, giving them a meadow-like appearance. Such swamps often border reed swamps on the land side, and encroach upon them as the reed plants build up land. With the sedges and grasses numerous other swamp-loving plants are found.

196. Swamp thickets.—A growth of shrubs or low trees may invade the sedgy swamp, giving rise to a thicket.

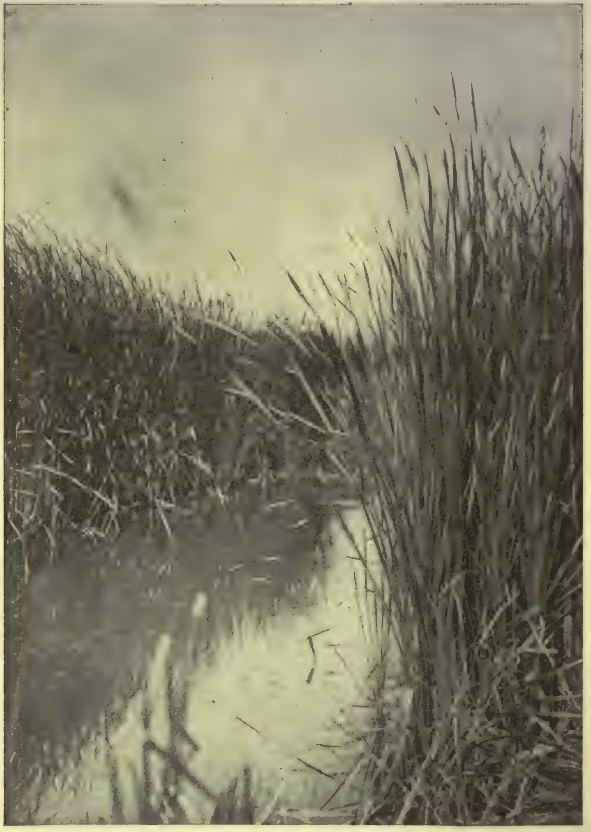

FIG. 304.—A reed swamp.—After KERNER.

These shrubs and trees are of very uniform type, being mainly willows, alders, birches, etc.

This series of associations, from pondweed associations

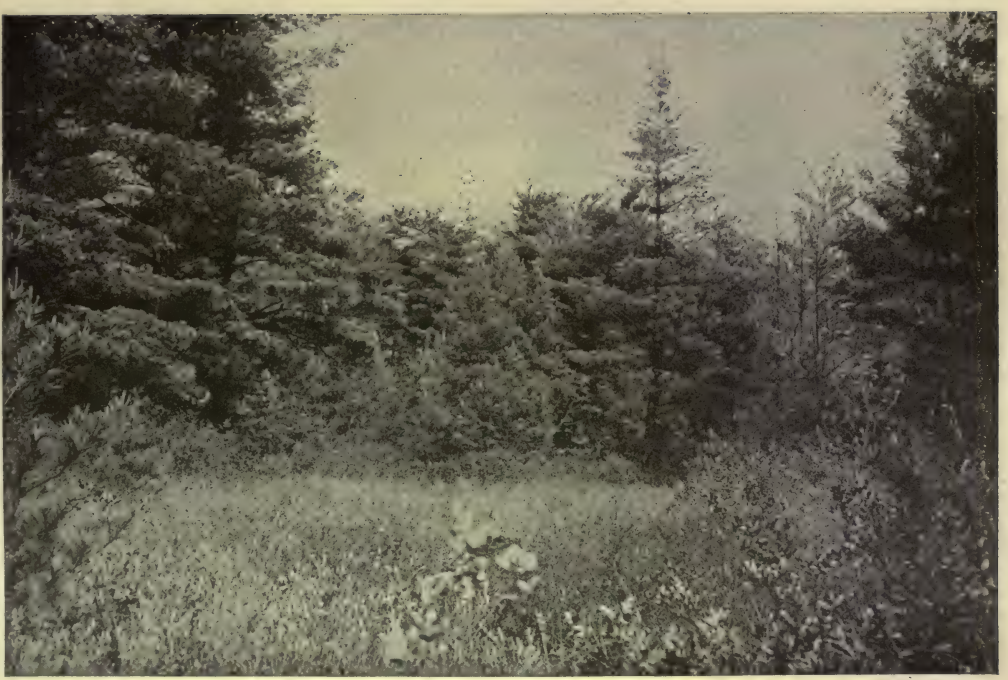

FIG. 305.—Peat-bog in pine forest, showing encroachment of young pines

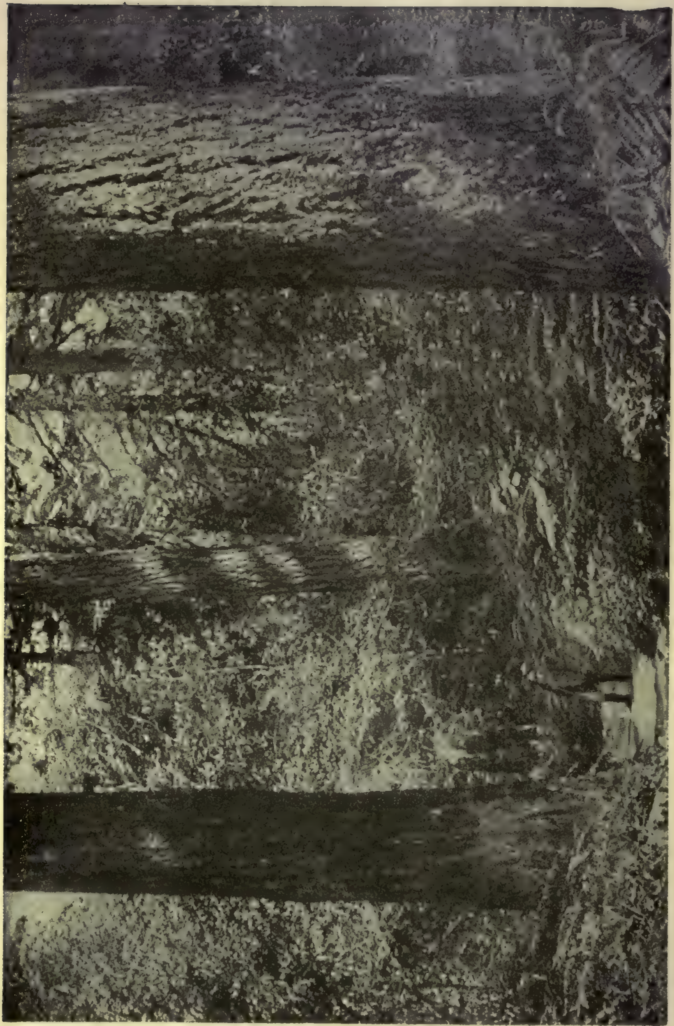

Fig. 306.—A swamp forest.

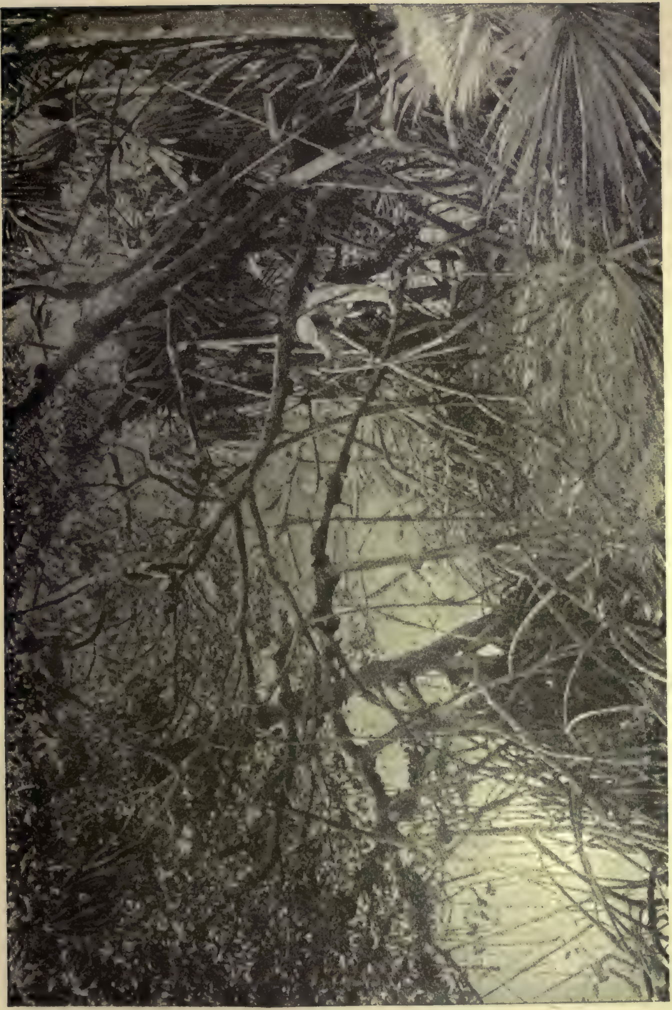

FIG. 307.—Mangroves, showing the numerous prop-roots.

to swamp thickets, is a very natural one, each one often passing gradually into the next.

197. **Peat-bogs.**—This is a peculiar kind of swamp association, characterized by the abundant growth of the bog- or peat-moss, and developed in undrained swamps. Growing out of the springy moss turf there are numerous peculiar plants, such as heaths (Fig. 305) and orchids, and the curious carnivorous plants (§ 20).

198. **Swamp forests.**—Often trees encroach upon peat-bogs, and a swamp forest is the result. The chief types in this case are the conifers, and on this bog-moss foundation there occur larches, certain hemlocks and pines, junipers, etc. The larch or tamarack is a very common swamp tree of the northern regions, usually occurring in small patches; while the larger swamp forests are composed of dense growths of hemlocks, pines, etc. (Fig. 306).

199. **Salt marshes and meadows.**—The salt marshes and meadows near the seacoast are well known. They lie beyond the reach of ordinary flood-tide, but the waters are brackish. In these marshes occur certain characteristic salt-water grasses and sedges, giving the meadow-like appearance; while associated with them there are numerous succulents, that is, fleshy plants, characteristic of brackish water.

200. **Mangrove swamps.**—This is the most vigorous salt-water association. Mangrove swamps occur along flat tropical seacoasts where the waters are quiet (Fig. 307). The mangrove is a tree of curious habit, advancing slowly out into the water by means of its prop-roots and peculiar seeds. The seeds germinate while still upon the tree, so that the embryos hang from the trees and then drop like plumb-bobs into the muck beneath, where they stick fast and establish themselves.

CHAPTER XXIII

XEROPHYTES

201. **Adaptations.**—The adaptations of plants to meet drought are numerous and striking. The meager supply of water available for the plant must not escape from it too freely, and hence most of the special adaptations are to check the loss of water. In addition to this, there is often developed water-storage tissue, which acts as a reservoir, receiving water at a time of supply and doling it out according to the needs of the plant.

Drought conditions vary in different regions, and may be grouped under three heads: (1) *possible drought,* which occurs at irregular intervals, or which in some seasons may not occur at all; (2) *periodic drought,* which occurs at regular intervals; and (3) *perennial drought,* which is a constant condition, as in arid or desert regions. For the first condition plants are poorly prepared, but by various temporary expedients may resist until the drought ceases. For the second condition plants are well prepared, enduring the regularly recurring drought as definitely as a regularly recurring winter. In the third condition plants not only must endure drought, but also must be able to work in such conditions.

Some of the conspicuous methods of protection against drought have been described (§ 17). These should be kept in mind when the following illustrations of xerophytic associations are considered.

202. **Rock associations.**—Certain plants are able to live upon rocks and boards exposed to direct sunlight. The conspicuous forms are lichens and mosses, which are found very commonly splotching rocks (Fig. 308) and old fences. Associated with them are often crevice plants, which send their roots into crevices and so gain a foothold.

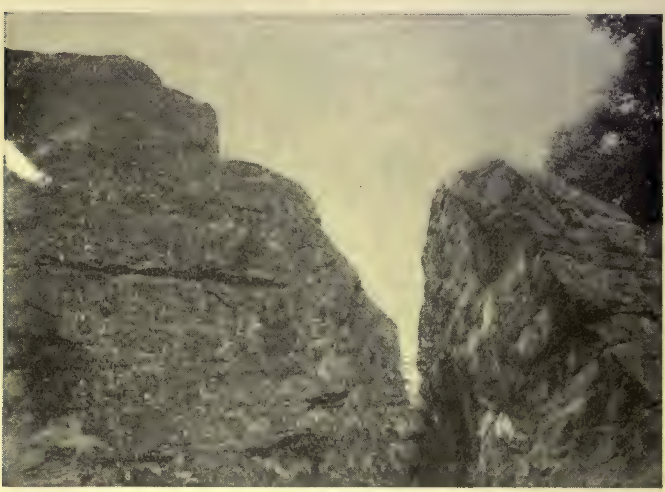

Fig. 308.—Rocks covered with lichens and mosses.

203. **Sand associations.**—The plants grouped together on dry, sandy ground are quite different in appearance from others, and such areas may be found in almost every neighborhood, at least along streams. On certain borders of the Great Lakes and on seacoasts an interesting succession of sand associations occurs. Nearest the water is the beach with such a poor display of plants that it looks bare.

Beyond the beach are the dunes, which are billows of sand that have been formed by the prevailing winds; and in many cases they are continually changing their form and are frequently moving landward (Fig. 309). In the case of these moving dunes a peculiar type of vegetation is demanded. Very few plants are able to live in such severe conditions, and these plants have developed at least two peculiar characteristics. One is that they are sand-binders; that is, the underground structures are extremely far-reaching, giving the plants a firm anchorage in the shifting sand. As soon as enough of the sand-binders have established themselves, a shifting dune becomes a fixed one. Another characteristic of such plants is that they are able to grow up through the sand after they have been engulfed. Along certain coasts where moving dunes encroach upon farms and villages and threaten to engulf them, great attention has been given to checking them by means of sand-binding plants.

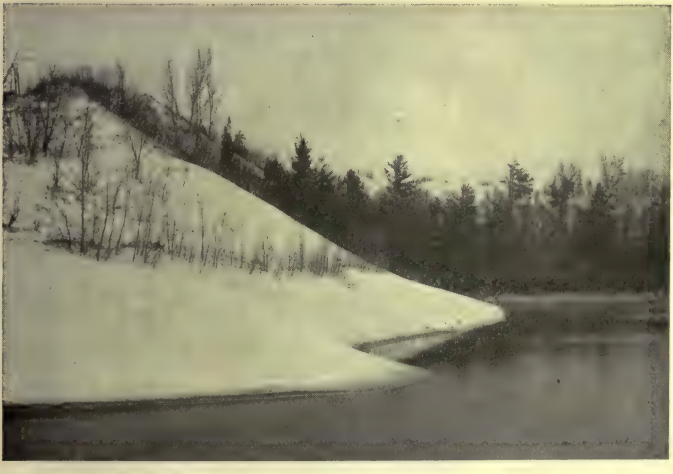

Fig. 309.—Dunes of Lake Michigan encroaching landward, in this case diverting Calumet River.

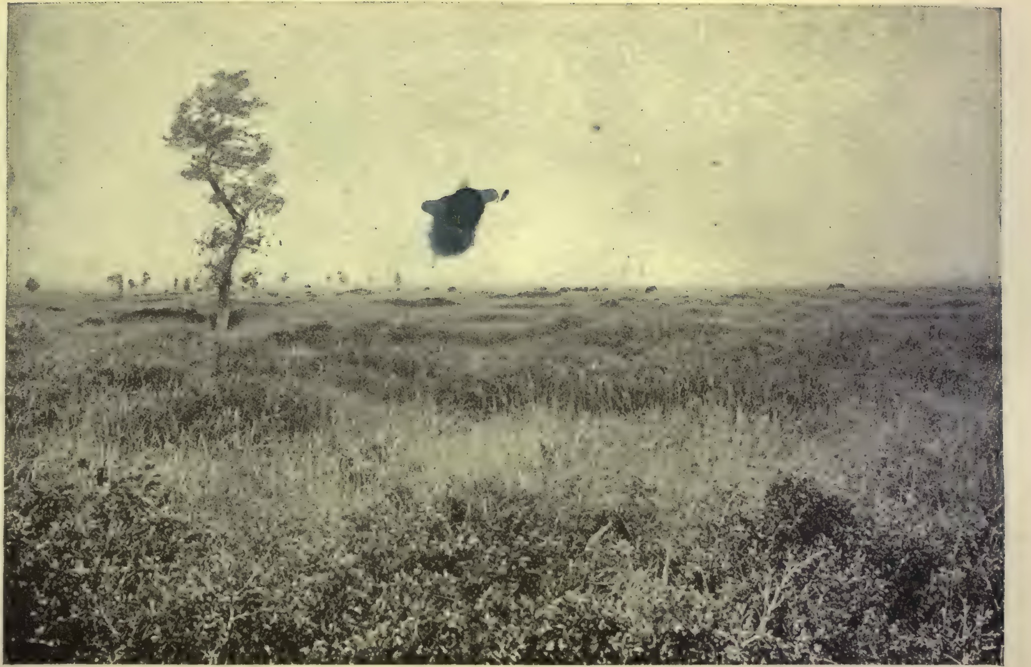

FIG. 310.—Characteristic view on the plains: the cottonwood in the foreground, and others dimly seen in the background, indicate spots of greater moisture or streams

The region of dunes may gradually pass landward into sandy stretches or fields, covered with tufted grasses, shrubs, and low trees.

204. **Plains.**—Under this head are included great areas in the interior of continents, where dry air and wind prevail. The plains of the United States extend from about the one-hundredth meridian westward to the foot-hills of the Rocky Mountains. Similar great areas are represented by the steppes of Siberia, and in the interior of all continents. On the plains of the United States the characteristic plant forms are bunch-grasses, that is, grasses which grow in tufts and do not form turf; and the low grayish shrubs called sage-brush (Fig. 310).

205. **Cactus deserts.**—In passing southward on the plains of the United States, the conditions are observed to become drier, until the cactus deserts are reached (Fig. 311). This region begins in western Texas, New Mexico, Arizona, and Southern California, and stretches far southward into Mexico. This vast arid region has developed a peculiar flora, which contains our most highly specialized drought plants. The numerous forms of cactus are the most characteristic, and associated with them are the yuccas and agaves. Not only are the adaptations for checking transpiration and for retaining water of the most extreme kind, but also there is developed a remarkable armature of spines.

206. **Subtropical deserts.**—In these areas drought conditions reach the greatest extreme in the combination of great heat and scanty water-supply. It is evident that such a combination is almost too difficult for plants to endure. That the very scanty vegetation is due to lack of water, and not to lack of proper materials in the soil, is shown by the fact that where water does occur oases are developed, in which luxuriant vegetation is found. The desert which stretches from Egypt across Arabia may be regarded as a

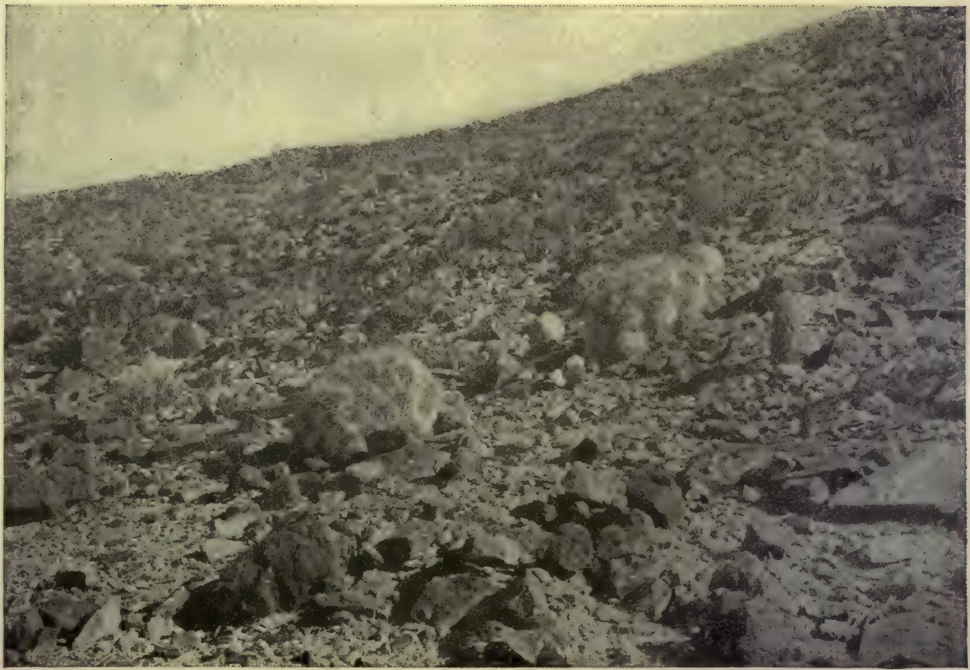

FIG. 311.—A cactus desert, showing the very rough, rocky soil with clumps of globular cactus forms.—After SCHIMPER.

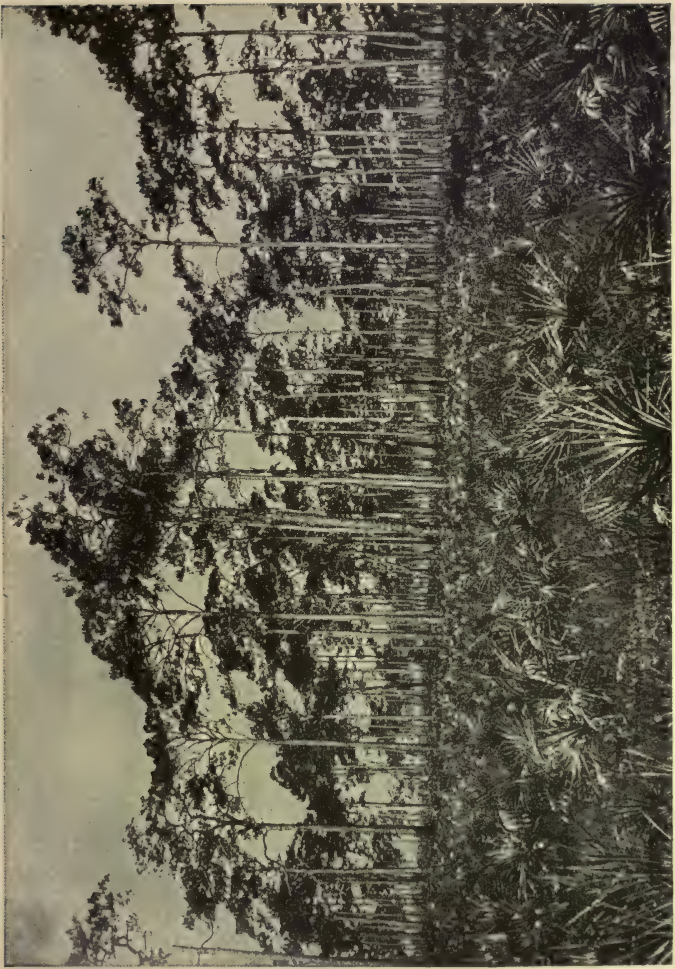

FIG. 312.—A grove of southern pines.—After SCHIMPER.

typical one; and the Desert of Sahara is another well-known illustration.

207. **Thickets.**—Xerophytic thickets are the most strongly developed of all thicket growths. They are specially characteristic of the subtropics, and may be described as scraggy, thorny, and impenetrable. Such thickets are well displayed in Texas, where they are called "chaparral"; and similar thickets in Africa and Australia are spoken of as "bush" or "scrub." In all of these cases the thicket is of the same general type, and is one of the most forbidding areas for travel.

208. **Forests.**—The most common xerophytic forests of the United States consist of conifers, especially of pines. They occur along the rocky slopes of the mountains, and on the vast sandy areas that border the Great Lakes and cover the Gulf States (Fig. 312).

209. **Salt steppes.**—In these areas, not only are the drought conditions continuous, but the water is alkaline. The salt steppes are interior dry wastes which probably mark the site of old sea basins. In the United States one of the most extensive of the salt steppes is the Great Salt Lake Basin. Another extensive alkaline waste is known as the Bad Lands, which stretches over certain portions of Nebraska and South Dakota.

210. **Salt and alkaline deserts.**—In these areas the water-supply is at its lowest ebb, and therefore is saturated with the characteristic salts of the soil. No worse combination for plant activity can be imagined than the combination of scanty water-supply and abundant salts. In consequence, such areas are almost, if not absolutely, devoid of vegetation. As illustrations, the extensive desert of the Dead Sea region and the Death's Valley in southern California may be cited.

CHAPTER XXIV

MESOPHYTES

211. **General characters.**—Mesophytes include the common vegetation of temperate regions. The conditions of moisture are medium, precipitation is in general evenly distributed, and the soil is rich in humus. This may be regarded as the normal condition for plants. It is certainly the arable condition, and best adapted to the plants which men cultivate. When for the purposes of cultivation xerophytic areas are irrigated, or hydrophytic areas are drained, it is simply to bring them into mesophytic conditions. Conspicuous among mesophytic associations are the following:

212. **Meadows.**—This term must be restricted to natural meadow areas, and should not be confused with artificial areas of the same name under the control of man. The appearance of such an area hardly needs description, as the vegetation is a well-known mixture of grasses and flowering herbs, the former usually predominating. Such meadows, of large or small extent, are very common in connection with forest areas and on the flood-plains of streams (Fig. 313).

The greatest meadows of the United States are the *prairies*, which extend in general from the Missouri eastward to the forest region of Illinois and Indiana. The vegetation of the prairies is usually composed of tufted grasses and perennial flowering herbs (Fig. 314). Unfortunately most of the natural prairie has been replaced by farms, and the characteristic prairie plants are not easily

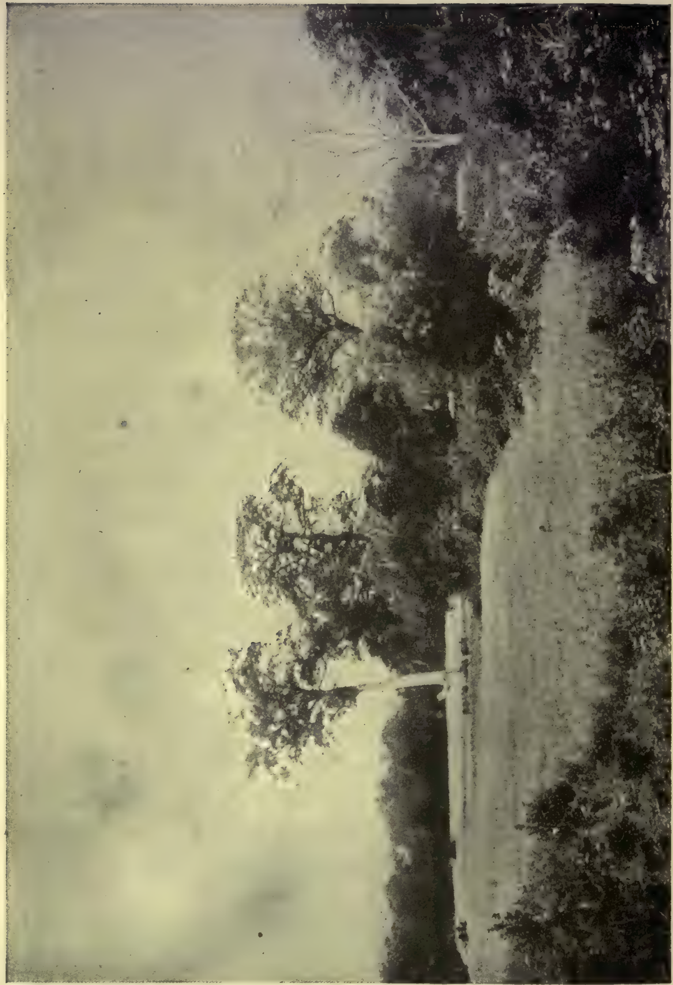

FIG. 313.—A small natural meadow, surrounded by trees and shrubs.—After SCHIMPER.

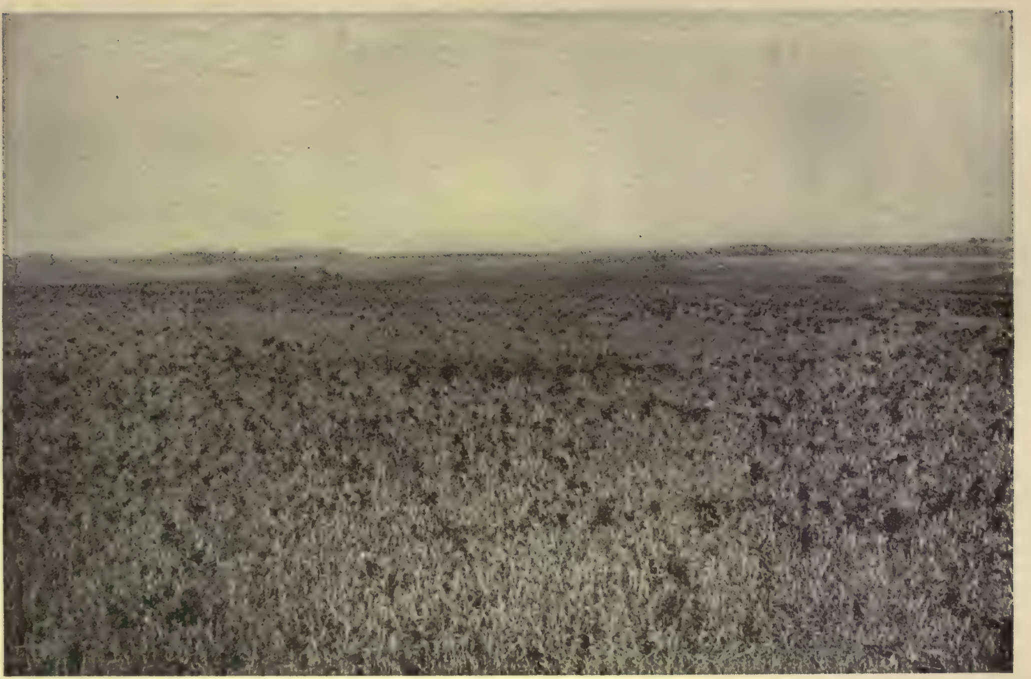

FIG. 314.—A prairie, showing the characteristic covering of grass interspersed with clumps of coarse herbs (showing dark in the picture).

seen. The flowering herbs are often very tall and coarse, but have brilliant flowers, as asters, golden rods, rosinweeds, lupines, etc.

The origin of the prairie has long been a vexed question, which has usually taken the form of an inquiry into the conditions which forbid the growth of a natural forest. Prairies are of two kinds at least: those due to soil conditions and those due to climatic conditions. The former are characteristic of the Eastern prairie region, and appear in scattered patches through the forest region as far East as Ohio and Kentucky. They are probably best explained as representing old swamp areas, which in a still more ancient time were ponds or lakes. All the prairies of the Chicago area are evidently of this type, being associated with former extensions of Lake Michigan.

The climatic prairies are characteristic of the Western prairie region, and are more puzzling than the others. Among the several explanations suggested, perhaps the most prominent is that which regards the absence of a natural forest on the Western prairies as due to the prevailing dry winds. The extensive plains farther West develop the strong and dry winds that sweep over the prairies, and this brings extremes of heat and drought, in spite of the character of the soil. In such conditions a seedling tree could not establish itself. If it is protected through this tender period it can maintain itself afterward. These prairies, therefore, represent a sort of broad beach between the Western plains and the Eastern prairies and forests.

213. **Thickets.**—Mesophytic thickets are not so impenetrable as xerophytic thickets (§ 207), and are usually developed as forerunners of forests. An illustration of this may be obtained by noting the succession of plants on a cleared area. After such an area has been cleared of its trees, it is overrun by herbs that develop rapidly from the seed, the so-called fireweed usually being conspicuous.

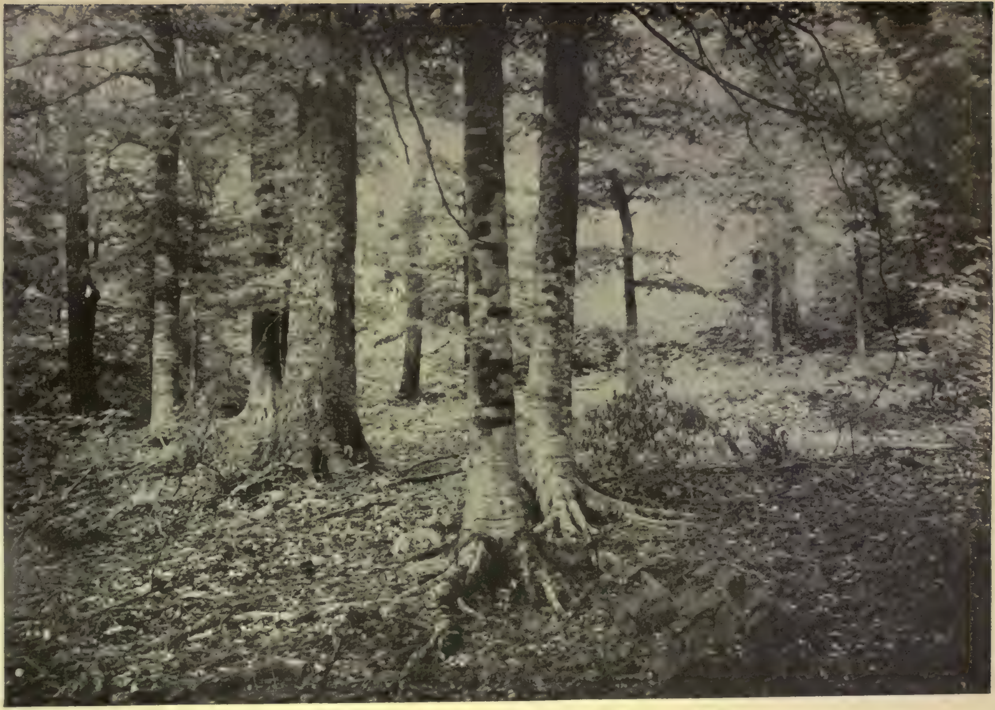

FIG. 315.—A beech forest in southern Indiana; a pure and dark forest.

Following the herb associations, there is a gradual invasion of coarser herbs and shrubby plants, forming thickets; and finally a forest growth may appear again.

214. **Deciduous forests.**—Deciduous forests are especially characteristic of temperate regions, the deciduous habit being an adaptation to the regular recurrence of winters. How the conifers contrast with the deciduous trees in this regard has been described (§ 19). The method of shedding leaves (§ 18), the characteristic autumnal coloration (§ 18), and the cultivation of the vernal habit by certain associated herbs (§ 27) have all been considered. The deciduous forest is known as the climax vegetation of the temperate regions, replacing all other associations if the conditions become favorable. Even a forest of conifers is gradually replaced by a deciduous forest when the conditions become mesophytic.

Deciduous forests may be pure or mixed. A common type of pure forest is the beech forest, which is a dark forest, the wide-spreading branches of neighboring trees overlapping so as to form a dense shade (Fig. 315). In such a forest, therefore, there is little or no undergrowth. Another pure forest, which belongs to drier areas, is the oak forest, which is a light forest, permitting access of light for lower plants (Fig. 316). In such a forest, therefore, there is usually more or less undergrowth. The typical American deciduous forest, however, is the mixed forest, made up of many varieties of trees, such as beech, oak, elm, walnut, hickory, maple, gum, etc.

Deciduous forests may be roughly grouped also as upland and flood-plain (river bottom) forests,the former being less luxuriant and containing fewer types, the latter being the highest type of forest growth in its region (Fig. 317). A few general illustrations may be given, which will enable the student to characterize the forests of his neighborhood.

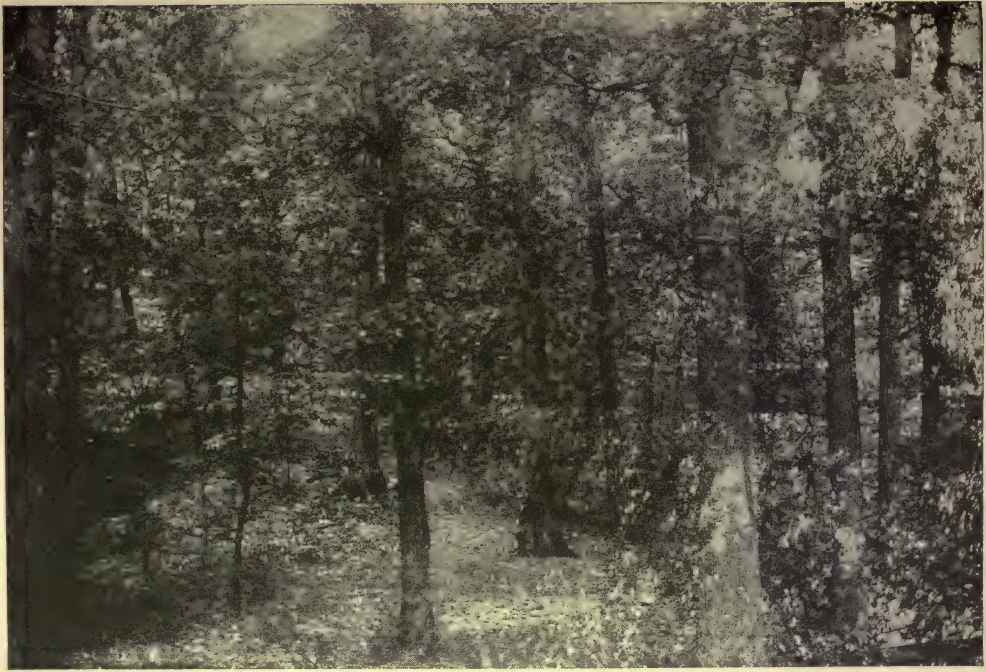

Fig. 316.—An oak forest in Tennessee; a pure and light forest, with undergrowth.

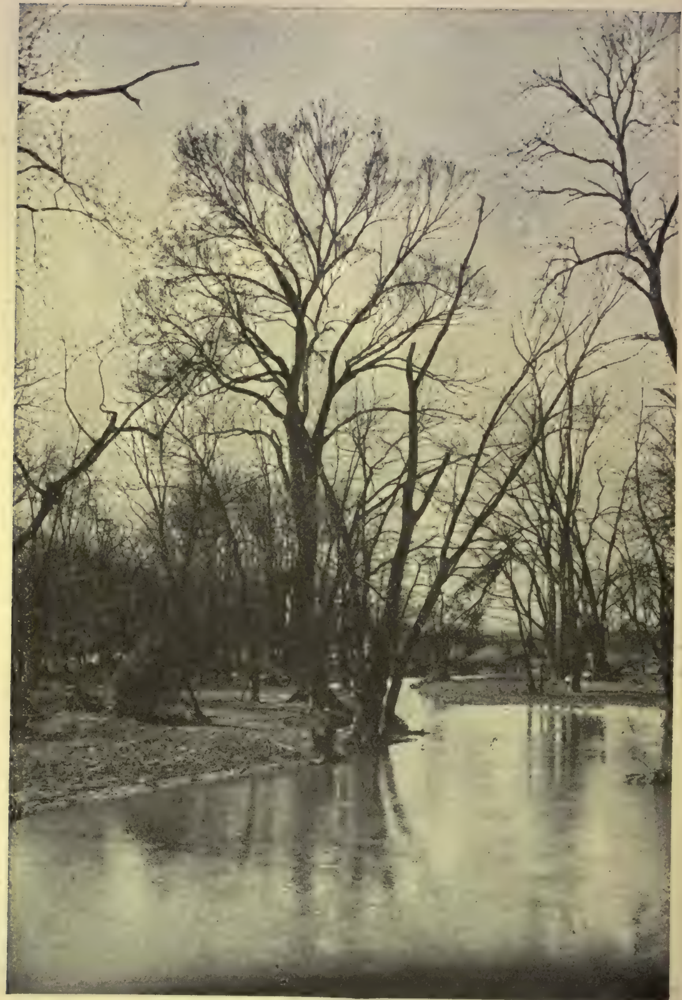

FIG. 317.—A mixed river bottom forest in northern Illinois.

In northern Illinois the upland forest is generally made up of white and red oaks and shellbark hickory; while the flood-plain forest contains twenty to twenty-five tree forms, prominent among which are the elms (white and slippery), linden (basswood), cottonwood, ash, silver maple, box-elder, walnut, and willows (Fig. 318).

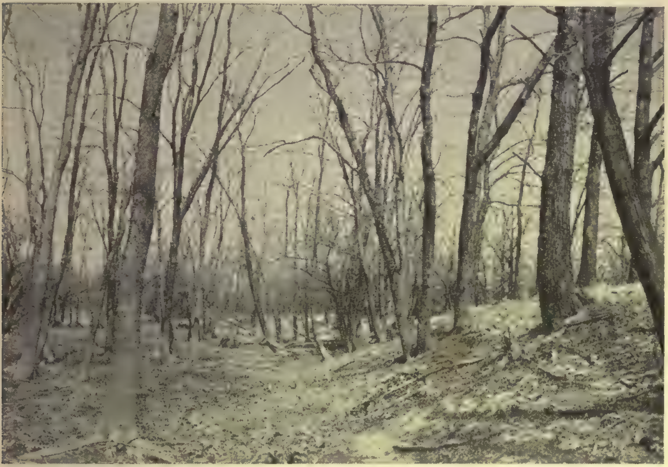

FIG. 318.—Junction between an upland forest (oaks on the slope to the right) and a flood-plain forest (on the level ground to the left).

Farther south, from central Illinois, Indiana, and Ohio southward, as well as in the Alleghanies, the flood-plain forests are the richest known, containing, in addition to the forms enumerated above, such prominent trees as sycamore, beech, sugar-maple, tulip-tree (white poplar), buckeye, hackberry, honey-locust, coffee-tree, etc.

In Michigan and Wisconsin the upland forests consist prominently of beech, sugar-maple, and hemlock, a characteristic mixture of deciduous and evergreen trees; while the flood-plain forests are scarcely at all developed.

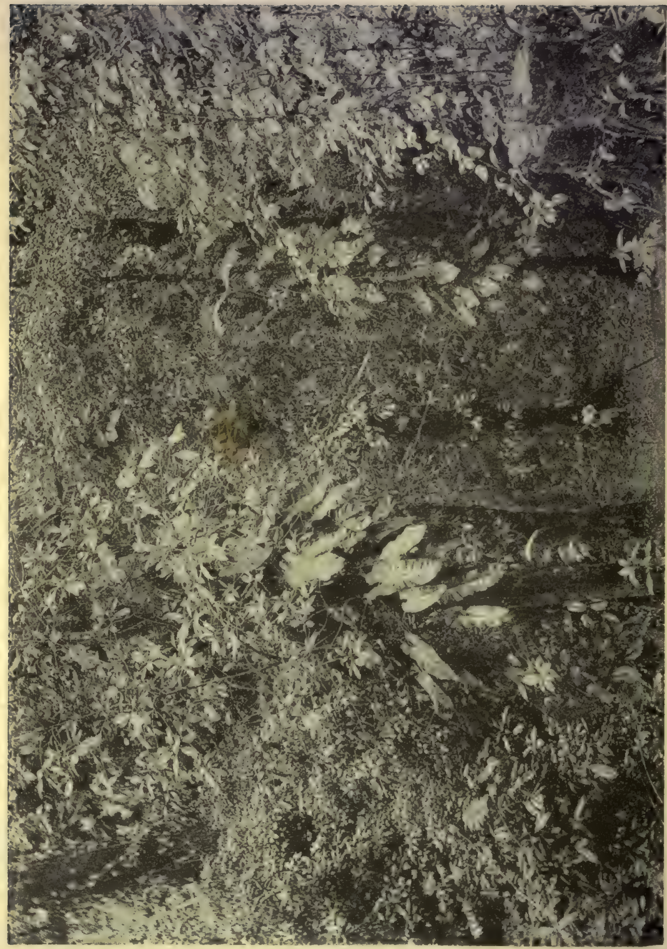

FIG. 319.—A rainy tropical forest.—After SCHIMPER.

In the Alleghany region and New England the upland forests are very extensive and complicated, grading from the rich flood-plain forests of the lower levels to the strictly xerophytic forests (pines and black oaks) of the higher levels, and dominated by various oaks, chestnuts, and hickories.

The flood-plain forests of New England are not so rich as those of the Alleghany region and the central West, the dominant forms being elm, linden, ash, maple, sycamore, tulip-tree, etc.

215. Tropical forests. — The forests of the rainy tropics may be regarded as the climax of the world's vegetation (Fig. 319), for the conditions favor constant plant activity at the highest possible pressure. Such great forest growths are found within the region of the trade-winds, where there is heavy rainfall, great heat, and very rich soil, as in the East Indies, and along the Amazon and its tributaries. So abundant is the precipitation that the air is often saturated and the plants drip with the moisture.

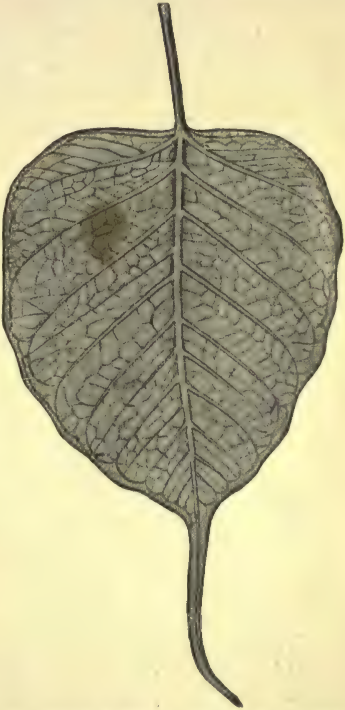

FIG. 320.—A gutter-pointed leaf of a rainy tropical forest.—After SCHIMPER.

The striking characteristics of the great mixed tropical forest are as follows: (1) There is no regular period for the development or fall of leaves, and hence there is no time of bare forest or of forests just putting out leaves. Leaves are continually being shed and formed, but the trees always appear in full foliage. (2) The density of growth is remarkable, resulting in a gigantic jungle, with plants at every level, interlaced by great vines and covered by perching plants. (3) Such forests display not only an immense number of individual plants, but also an extraordinary number of species. (4) The various devices for shedding the abundant rain from the leaves give to them a very characteristic appearance. Prominent among them are the gutter-pointed leaves, the tip being prolonged as a sort of spout and the veins depressed, the whole surface of the leaf resembling a drainage system (Fig. 320).

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